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NUTRIENT CHEMISTRY OF A LARGE, DEEP LAKE IN SUBARCTIC ALASKA

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The primary objective of this project was to assess the state of the water quality of Harding Lake, and to attempt to predict the effects of future development within its watershed. Since the major effect of degradation of water quality due to human activity is the promotion of nuisance growths of plants, the major emphasis was placed on measurements of plant growth and concentrations of the major nutrients they require. Planktonic algal growth was found to be low, below 95.6 gm/m^2/year, and the growth of submerged rooted plants was found to be relatively less important at approximately 1.35 gm/m^2/year. Measurements of the growth of attached algae were not conducted, therefore the relative importance of their growth is currently unknown. A model for predicting the effect of future real estate development in the watershed was modified and applied to this lake. This model adequately describes current water quality conditions, and is assumed to have some predictive ability, but several cautions concerning application of this model to Harding Lake are discussed. A secondary objective was to study the thermal regime of a deep subarctic lake. Hydrologic and energy budgets of this lake are attempted; the annual heat budget is estimated at $1.96\times10^4 \pm 1.7\times10^3$ cal/cm^2. The results of a study of domestic water supply and waste disposal alternatives in the watershed, and the potential for enteric bacterial contamination of the lake water are presented. Limited work on the zooplankton, fishes and benthic macroinvertebrates of this lake is also presented.

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A model for predicting the effect of future real estate development in the watershed was modified and applied to this lake. This model adequately describes current water quality conditions, and is assumed to have some predictive ability, but several cautions concerning application of this model to Harding Lake are discussed.

A secondary objective was to study the thermal regime of a deep subarctic lake. Intensive water temperature measurements were made throughout one year and less intensive measurements were conducted during two additional years. The possibility that this lake may occasionally stratify thermally under the ice and not mix completely in the spring was discovered. The implications of this possibility are discussed for management of subarctic lakes. Hydrologic and energy budgets of this lake are attempted; the annual heat budget is estimated at $1.96 \times 10^4 \pm 1.7 \times 10^3$ cal/cm^2.

The results of a study of domestic water supply and waste disposal alternatives in the watershed, and the potential for enteric bacterial contamination of the lake water are presented. Limited work on the zooplankton, fishes, and benthic macroinvertebrates of this lake is also presented.

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SECTION 1

INTRODUCTION

Harding Lake is centrally located in Interior Alaska at 64°25' N, 146°50' W, adjacent to the Tanana River and abutting the Tanana-Yukon uplands. Fairbanks, the second largest urban area in the state with a population of approximately 65,000, is 73 km to the northwest and access to the lake is afforded by one of the primary highways of the state. Paralleling the highway in this area and passing within a few kilometers to the north of the lake is the Trans-Alaska Pipeline and its right-of-way. This lake is the closest lake to Fairbanks having sufficient size (988 hectares) and depth (43 m maximum, 16 m mean) for recreation in the Tanana Valley.

Lakeside development began very early in the history of the region when the present highway was a trail. The relatively early importance of the lake in the Fairbanks area is indicated by the renaming of the lake in 1923 for President Warren G. Harding. The aboriginal name for the lake had been Salchaket Lake. Building of first-tier lakeside dwellings has been intense with occupancy of private lots on nearly 75% of the lakeshore (Larson, 1974). Development is now proceeding in second-tier lots in many sections.

This development has created concern for the water quality of the lake. In 1966, Alaska State Division of Public Health scientists discovered possible coliform bacteria contamination of the lake. Ecologists (Weeden, 1971; Nyquist, 1971), noting the density of near-shore development and aware of the bacterial contamination of the lake, became concerned that the lake might lose its recreational potential. Lakeshore residents also expressed concern over deterioration of the aesthetic qualities of the lake and its environs, with some reports of "blooms" of floating algae and many complaints about waste disposal practices. These signs all pointed to cultural (accelerated) eutrophication of the lake from nonpoint discharges suspected to be emanating from septic infiltration and surface run-off along the developed shoreline.

Although there had been infrequent, short-term studies of the lake by various investigators, especially students of the University of Alaska at Fairbanks, there were no comprehensive data on the nutrient status and trophic state of the lake. Attendant to the specific problem of assessing cultural eutrophication of the lake, there was the general need to develop fundamental limnological knowledge about the physical, chemical, and biological regimes of deep subarctic lakes. Recent studies of a deep lake in the Canadian arctic have been reported (Schindler *et al.*, 1974; Welch and Kalff, 1974; Rigler *et al.*, 1974), but with few exceptions (Hobbie, 1964), there is not even rudimentary data on most deep lakes in the Alaskan arctic and subarctic and references have been made to the scarcity of information on arctic lakes (Livingstone, 1963; Hobbie, 1973). The extensive efforts of the Tundra Biome Program were largely confined to tundra ponds and only recently, in post-Biome studies, have large lakes come into the forefront of this effort.

This fundamental knowledge is particularly important with regard to the thermal mechanics of such lakes. The extreme annual temperature variation in areas such as the Alaskan intermontaine plateau produces thick ice cover over a large part of the year in a cycle broken by nearly temperate summer conditions. An equally eccentric light regime in concert with this seasonal temperature cycle may produce unusual hydromechanical situations at times of seasonal changeover. Thus, a study of the thermal regime of Harding Lake was seen to be a significant contribution to knowledge of large arctic and subarctic lakes.

The limited scale of Phase I work provided an important conclusion, namely, that concentration values of nearly all plant nutrient parameters studied were near the detection limits of standard methods. This necessitated selecting more sensitive methods or looking to collective parameters to obtain information on the nutrient status of the lake. It also became apparent that the low levels of plant nutrients in the water column probably meant that the nutrient status of the sediments and the rooted vascular macrophytes were important parameters to be considered.

The establishment of a permanent field station at the onset of Phase II marked the beginning of intensive biological studies, especially measurement of algal production and ancillary work on vascular hydrophyte populations. Studies of the higher trophic levels were begun or advanced, with some attention given to zooplankton dynamics, benthic macroinvertebrates, and certain aspects of the fish community of the lake.

During Phase III, completion of the chemical nutrient work focused on potential loading of the lake system from its watershed. A theoretical approach to questions of cultural eutrophication has often concerned measurements of the macronutrients necessary for algal growth and the algal response to their presence. More recently Vollenweider (1971) and others have developed sophisticated models to predict the effects of specific nutrient loading of lakes de-emphasizing the role of plant nutrients dissolved in the lake water in favor of emphasizing the role of their potential supply by the contributing watershed. Ancillary to the focus on the role of the watershed, a limited amount of work was addressed to the phenomenon of the dropping water level which was of great concern to the lakeshore land owners. More detailed studies of the vernal thermal characteristics of this lake were also carried out during this phase. An ancillary study which concerned benthic invertebrates as trophic indicators in Alaska was also completed during this phase and that study treated information concerning this lake (LaPerriere, 1975).

When our analyses showed an apparent under-ice dormancy of the phytoplankton, as indicated by very low productivity but relatively high standing crop (inferred from chlorophyll a measurements), the importance of algal heterotrophy was considered. Rodhe (1955) discusses this phenomenon concerning lakes in high latitudes. Thus, an experiment to measure an aspect of algal heterotrophy was chosen to conclude the field work on November 14, 1975.

SECTION 2

CONCLUSIONS

1. The falling water level of Harding Lake, which is a serious concern of the lakeshore residents, is most probably due to the natural cycle of the amount of precipitation.

2. Harding Lake may be classified as dimictic, but on rare occasions it may not reach complete saturation with oxygen in the spring when thermal stratification, initiated at the end of the ice-cover period, is not broken because of absence of wind.

3. Concentrations of plant nutrients C, N, and P are currently moderate in Harding Lake, but future management decisions should protect the lake from additions of these nutrients.

4. Harding Lake supports low algal production comparable to other oligotrophic lakes of high latitudes. Reports of visible algal blooms on Harding Lake can most likely be attributed to tree pollen that covers the surface in the spring.

5. The growth of vascular aquatic plants is relatively less important than the algal growth of Harding Lake.

6. Application of a lake management model for the effects of nutrient loading on algal growth adequately describes peak growth, which occurs under the ice in spring. Should increased loading change algal succession patterns so that peak growth occurred in summer, visable deterioration of water quality would occur.

7. Heterotrophic algal growth may be important in this lake during winter when light penetration is low due to heavy ice and snow cover and to the short daylight period.

8. Zooplankton biomass appears to be highest in late summer at about ten times winter values.

9. The community of benthic chironomids found in this lake helps to classify it as oligotrophic.

10. Bacterial contamination detected between 1966 and 1971 was most likely due to improper sewage disposal methods at the state and the U. S. Army recreational areas. At both areas pit privies were replaced by vault toilets between 1970 and 1972, and during 1973 no excessive counts were detected near either recreation area.

SECTION 3

RECOMMENDATIONS

1. Further research should be conducted on the potential for monomixis in deep subarctic lakes. Lakes more productive than Harding could suffer summer oxygen content problems following a spring during which mixing was not complete and the deep waters were not reoxygenated.

2. The hydrology of Harding Lake should be studied in some detail, both to allow measurement of the water retention time and to provide those who would manage the lake level with predictions of the results of certain actions. Japanese scientists from the Institute of Low Temperature Science of Hokkaido University are attempting to obtain funds from the Japanese government to study the hydrology of Harding Lake and to take and examine a 20-m core of its sediments.

3. Research should be conducted on the relative importance of the benthic algae as primary producers in subarctic lakes. This production has been found to be relatively more important than that of phytoplankton in certain lake studies.

4. The sediments of Harding Lake should be studied to ascertain their role in the cycling of nutrients into the dissolved phase.

5. Further research should be conducted on heterotrophic algal production in subarctic lakes.

6. Research should continue concerning the use of chironomids as trophic state indicators for lakes of subarctic Alaska. This research should be of both a taxonomic and ecological nature.

7. Food-habit and production studies should be conducted on the fishes of Harding Lake. Research should also be carried out on production of zooplankton in this lake.

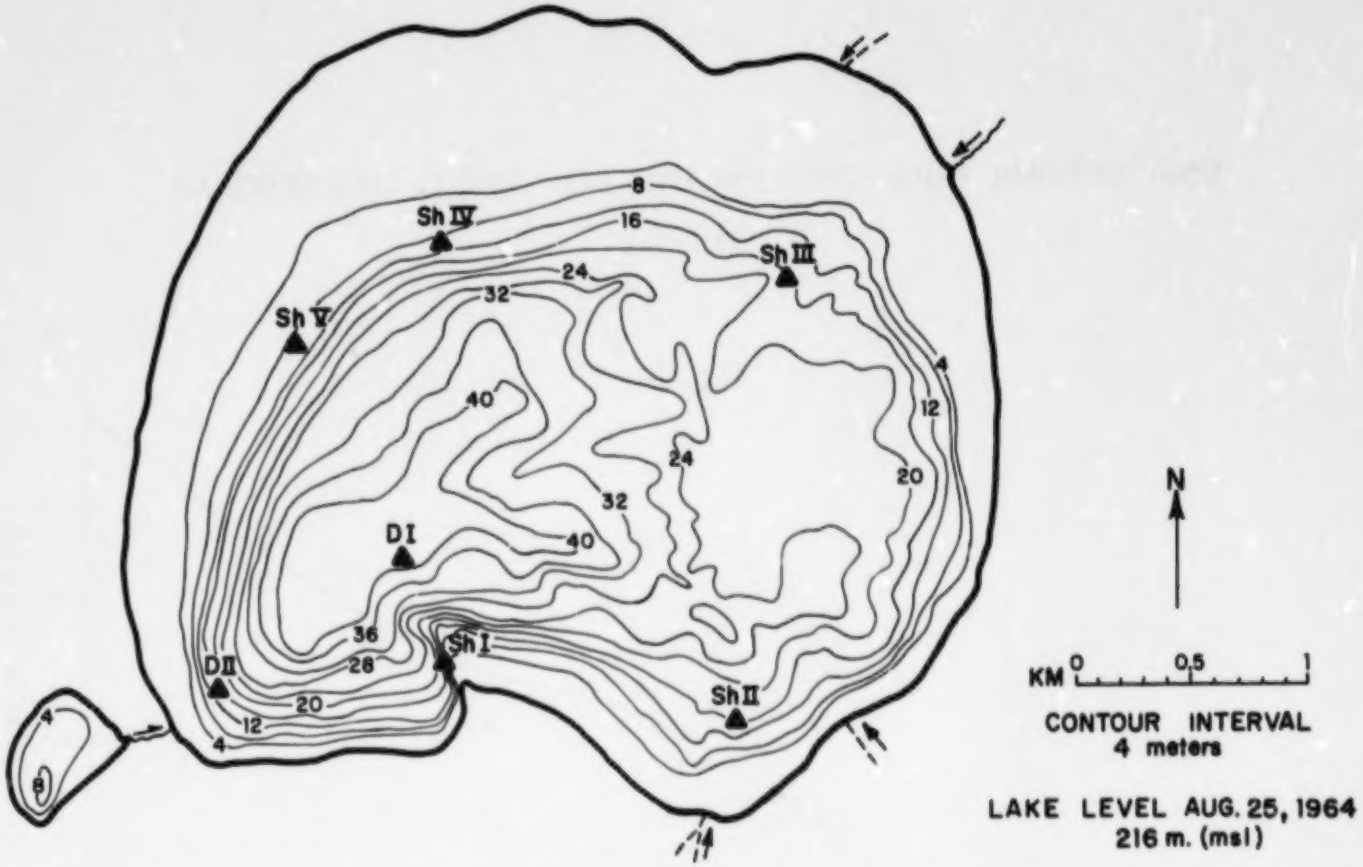
8. As the real estate surrounding Harding Lake continues to be developed, the state agencies responsible should recommend pumped vault or incinerating toilets prior to the time when a system of central treatment becomes economical. This action would protect the lake from one source of increased nutrient loading as well as from bacterial contamination. The use of pit privies or septic tanks should be prohibited in areas where the soil is unsuitable for proper operation.

SECTION 4

DESCRIPTION OF STUDY AREA

The geomorphological setting and the surface geology of the Harding Lake area have been described in a thesis by J. Michael Blackwell (1965), who also, in the course of his study, mapped the morphology of Harding and Little Lakes (Figure 1) as well as that of Quartz, Birch, and Chisholm Lakes of the same formation group. His major conclusion was that these lakes were most probably formed during the Delta (Illinoian) glaciation when aggradation of the Tanana River drowned tributary valleys. His work gives good evidence that the reasons that Harding Lake is so much deeper than its sister lakes, Birch and Quartz, the major lakes of nearby valleys, are because of more recent tectonic activity and reduced infilling. He found strong evidence of a linear fault along the deep axis of the lake and some evidence in the silt on terraces north of the lake of an ancient sudden rush of water from the lake. He speculates that the lake has filled in with sediments to a far lesser degree than the sister lakes due to the small size of the contributing watershed and perhaps to a lesser deposition of eolian silt on its hills.

Morphometrically, Harding Lake (elevation 217 m) is very close to being conical in shape. The hypsometric curve is presented in Figure 2. The ratio of mean to maximum depth ($\bar{z}/z_m$) is 16/43 = 0.37; the volume is $1.59 \times 10^8 m^3$; the volume development is 1.12; and the relative depth is 2.4%. The surface, 988 hectares in area, has a shoreline development index of 1.08 indicating how nearly circular it is in shape. The average slope for the lake is 2.4% or 24 m/km, but the lake contains extensive shallows with 33% of the surface area underlain by water of 5 m or shallower. The drainage basin of the lake covers slightly more than 2,000 hectares giving an extremely low potential watershed input. It should also be noted that in this area the mean annual precipitation is only 30.5 cm, with a mean annual snowfall of 127 cm, accounting for about a third of the annual volume. Of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4 meters
LAKE LEVEL AUG. 25, 1964
216 m. (msl)

FIGURE 1

MORPHOMETRIC MAP OF HARDING LAKE (AFTER BLACKWELL, 1965) WITH SAMPLING STATIONS INDICATED. DOTTED LINES INDICATE INTERMITTENT DRAINAGES.

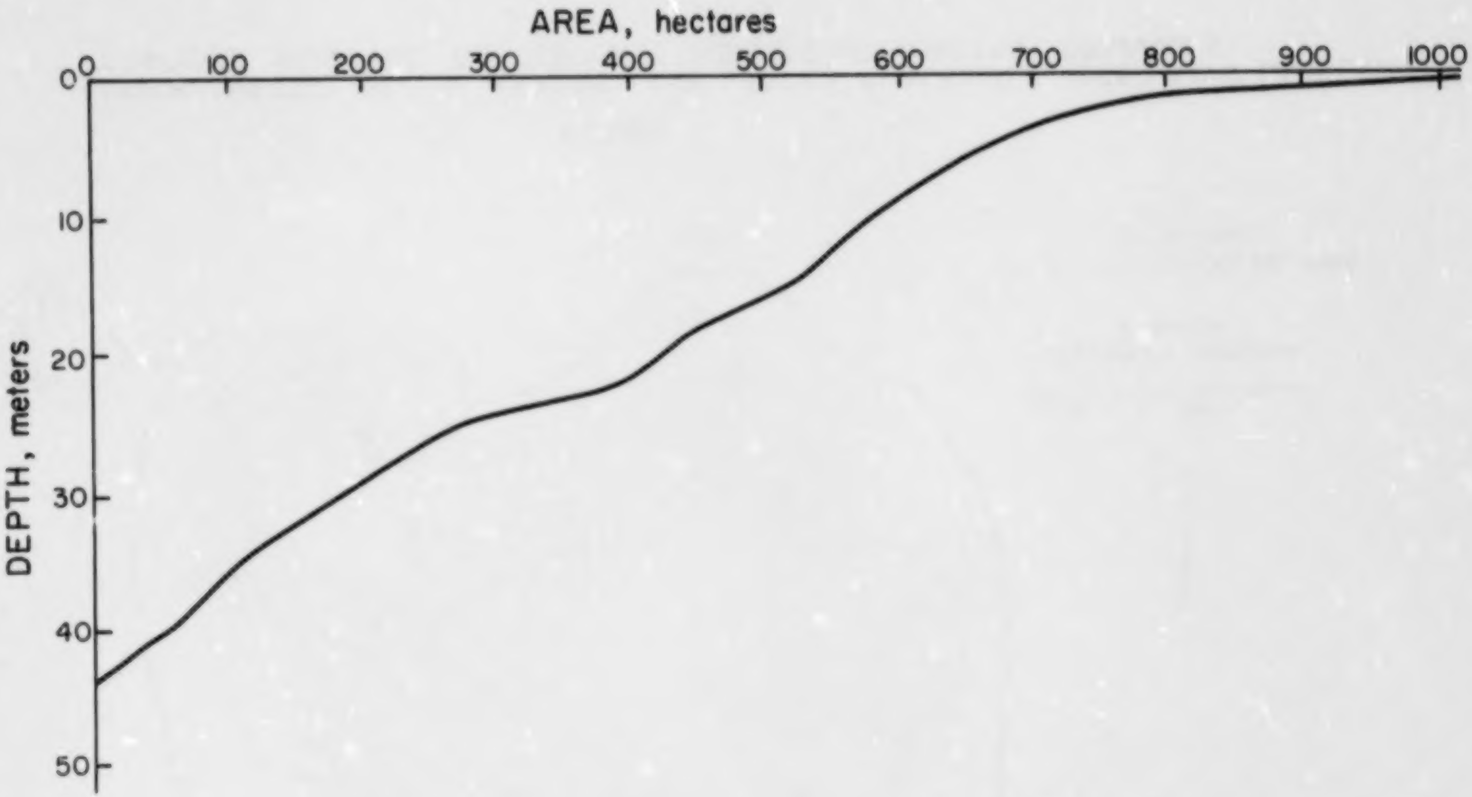


FIGURE 2

HYPSOMETRIC CURVE FOR HARDING LAKE (after Blackwell, 1965) the snowpack, an estimated 20-30% is measurable as runoff, the difference being intercepted or evaporated (Guymon, G. L., 1973, personal communication).

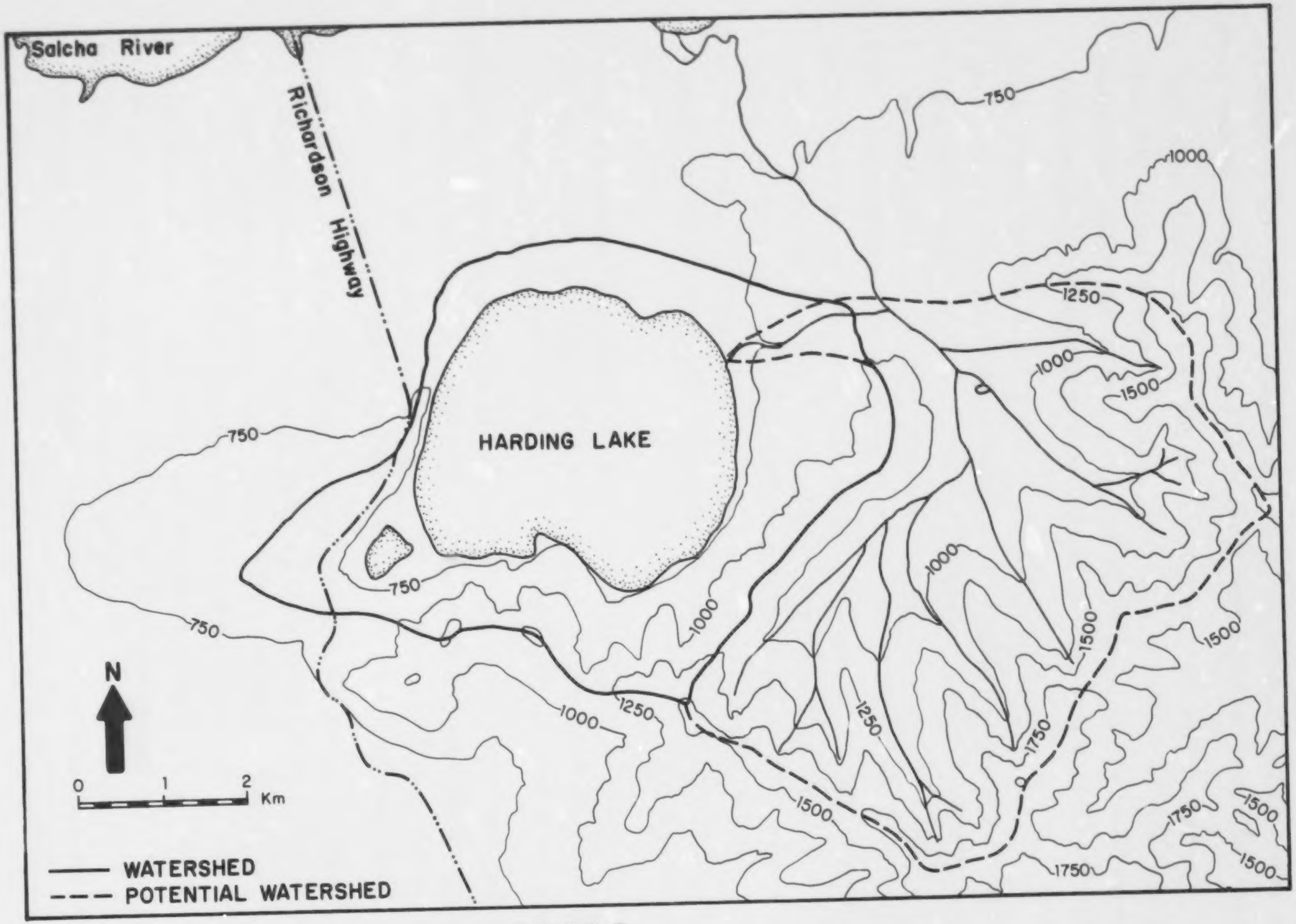
Continuous flow into the lake is limited to a fractional cubic meter per second provided by the undefined, swampy drainage of Little Lake and another small stream draining the northeast area of the basin. All other drainages exhibit flow only during snowmelt or infrequent heavy rainfall.

A limited study of the hydrology of the inlet on the northeast by our group has shown that at one time the drainage basin included a section we have named the potential watershed (Figure 3). This was seen to be a possibility upon examination of all available USGS maps of the area, some of which showed the stream at the northeast entering the lake and others which showed the stream diverging with one branch flowing out to the Salcha River. Tracing that stream on foot our hydrologists have found the branch to the Salcha River to contain standing dead trees indicating that it is somewhat recent in development. Attempts to age these trees and nearby controls by increment boring, however, have not proved possible because of interpretation difficulties.

Information on the soil types in the Harding Lake watershed are available in Schoephorster (1973). Very limited information concerning the shore sequence of plant cover is presented by LaPerriere and Robertson (1973).

The temperature regime of the area may be characterized as extreme with a mean minimum January temperature of -27°C, with extreme lows of -53°C; a mean maximum July temperature of 22°C, and extreme highs of 32°C; and a mean annual temperature of -5°C (Johnson and Hartman, 1969).

Snowfall is generally concentrated in the period after freeze-up (Watson *et al.*, 1971), diminishing with the onset of winter conditions. Winters are characteristically clear with little wind. Occasionally, however, lake ice may be blown free of snow during the fall period. This was the case in 1973, resulting in large wind-swept areas on Harding Lake. The snowfall during that winter was below the 127-cm annual average, therefore the possibility of occasional light penetration into the ice covered lake in fall and winter was demonstrated but observations through the winters of the study did not confirm this possibility.


Salcha River
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WATERSHED
POTENTIAL WATERSHED

FIGURE 3
WATERSHED MAP FOR HARDING LAKE

As a part of the study by Larson (1974), the shorelands around Harding Lake were studied to determine the extent of development and the types and conditions of sanitation facilities existing. This survey included identification of sewage disposal practices, water supply practices and the gathering of descriptive information relative to characterization of development.

The development area of Harding Lake contains some 400 individual land parcels of which 262 are lake-front lots. Nonetheless, some 38% of the shoreline of the lake is undeveloped and most of this is in some form of public ownership. In general, the shoreline of Harding Lake is considered to be highly developed when compared with recreation areas in the conterminous United States. Land parcels at Harding Lake are small with a mean size of 2,216 m^2. Eighty percent of the lots at Harding Lake have lake frontage of less than 30 m, and 77% of the cottages on lots at Harding Lake have setbacks of less than 23 m from the shoreline. Usage of private cabins at the lake occurs primarily during the summer months. The average usage rate is about 46 days which is substantially less than the average reported for second homes in the United States. Total cabin usage is approximately 23,000 people-days for a one-year period.

Five larger recreational facilities are located on the shores of Harding Lake and they occupy a total of 1,900 m of the shoreline. Primary use of these facilities occurs during the summer months and each has an associated swimming area. These include the Farthest North Shriners' Club, Camp Clegg (Girl Scouts of America), Camp Bingle (Presbyterian Youth), a U. S. Army recreation area, and a state recreation area. The state recreation area occupies some 975 m of lake shoreline and consists of the public bathing beach, 89 campground units, 63 picnic units, a general store concession and several sports activity fields. During fiscal year 1973, a total of 50,636 people visited the Harding Lake recreation area which makes it the second most visited site in the Alaska park system.

Water supplies at Harding Lake are quite varied with the most popular method being the transport of water to the lake in containers. Additionally, potable water is supplied by a spring near the lake and through nine individual wells. Untreated lake water is commonly used for some purposes, including cleaning, flushing, and washing.

A large number of sewage disposal methods are used at Harding Lake; however, no community sewage collection or treatment exists. Disposal methods include the use of privies (almost 80%), chemical toilets, cesspools, septic tank systems, holding tanks, and incinerator toilets. Some of the soil types in the Harding Lake area are considered to be extremely poor relative to soil treatment of wastewater discharge and pit privies and septic tank systems should be discouraged in such areas. It is believed that the best alternative sewage disposal method for the control of wastewater discharge would be one of collection and central treatment. It is recognized, however, that such a system may be impractical because of remoteness and a relatively small seasonal population. In general a lack of satisfactory shoreland zoning ordinances, especially with regard to setback requirements, exists.

SECTION 5

MATERIALS AND METHODS

GENERAL

Field crews were transported to sampling stations by boat during the ice-free season and by snowmachines when the ice cover had formed. The boat ordinarily used was a (7.3-m) flat-bottomed boat powered by a 50.7 horsepower (metric) outboard motor. The bow of the boat was fitted with a crane and winch for lowering and raising heavy equipment. The snowmachines were equipped with sleds for hauling equipment, and one sled was a metal facsimile of a dogsled allowing one rider at the rear.

Trips onto the unstable ice of late spring were made on foot by personnel wearing neoprene wet suits, hauling equipment in a 2.7-m inflatable rubber boat. Profiles were run at stations located by sighting to landmarks from boat or snowmachine and comparing depth, sounded by sonar, to the morphometric map. (Figure 1).

CLIMATOLOGY

Climatological data were collected intensively during the summer season of 1974. Precipitation data were collected daily using a standard 20.3-cm (8") diameter rain gauge containing a funnel collector allowing measurement to the nearest .025 cm (.01").

Daily high and low air temperatures were measured using standard U. S. Weather Bureau thermometers mounted on stainless steel backs and a Townsend support. These were housed in an all-wood instrument shelter built to Weather Bureau standards.

To measure pan evaporation, an evaporation station was set up in an open area near the permanent field station. The station consisted of a United States class A pan 25.4 cm (10") in depth and 120.65 cm (47.5") in diameter mounted on an open framework about 10.2 cm (4") above the ground, allowing air to circulate under the pan. A hook gauge inside a stilling well was used to measure evaporation and wind movement over the pan was measured with a contact anemometer reading in miles of wind movement. Pan water surface temperatures were measured with a shielded floating maximum-minimum thermometer. Relative humidity was measured using a standard sling psychrometer.

All instruments were installed and measurements taken according to procedures outlined by the World Meteorological Organization (1970).

PHYSICAL LIMNOLOGY

Depth, Temperature, Electroconductivity, pH, and Dissolved Oxygen

Depth profiles of the lake for temperature, dissolved oxygen, hydrogen ion and conductivity were determined *in situ* with a Martek Mark II Water Quality Monitoring System. Temperature is determined both separately and in conjunction with the oxygen subunit of this system. Depth is measured by a diffused silicon diaphragm pressure transducer.

The system includes a transducer array on a 46-m electrical cable and a control/display unit. Power is provided by a battery pack in the control/display unit, with outputs read on 8.4-cm (3.25") taut-band meters with mirrored scales which give maximum stability under pitch and roll. Range switches on depth, oxygen, pH, and conductivity allowed fairly accurate determination of these values, but the lack of a range switch for either temperature scale was found to be a serious deficiency.

The hydrogen ion concentration as its negative logarithm, pH, is determined by a sealed glass Ag-AgCl cell with pressure equalization and temperature compensation and a reference electrode. The sensor unit also includes a preamplifier to convert the high impedance output of the glass electrode to a low impedance signal for transmission through the cable. The calibration functions include zero, asymmetry, and slope which allow the calibration and span to be set accurately. The calibration procedure is conducted in the laboratory prior to field work. The pH unit is extremely stable and may be used for long periods without recalibration as was confirmed by frequent checks with buffer standards. As the cell output is temperature compensated, measurements through the thermocline were possible without extensive equilibration time.

Dissolved oxygen is determined by a pressure-equalized polarographic oxygen electrode. The electrode is equipped with a vibrating-wand stirring mechanism to create a constant flow across the electrode face to prevent depletion of oxygen at the electrode. This stirring unit malfunctioned several times and, until repaired, necessitated manual movement of the electrode with the cable until a constant output was obtained. Results from summer of the third year are in error and will not be reported since the pressure-equalizing diaphragm failed, resulting in dilution of the supporting electrolyte upon immersion.

Where necessitated by sensor failure and for calibration purposes, oxygen was determined by Winkler titration according to standard methods (APHA, *et al.*, 1971). A stainless steel sewage sampler was utilized to obtain samples. Since the oxygen was at or near saturation, displacement of air from the sampler was not believed to be a significant source of error, particularly since the scale of the oxygen sensor only allows estimation to 0.1 mg/l and is accurate to no more than 0.2 mg/l. Calibration of the sensor was usually conducted by the temperature-saturation method.

Electrical conductivity is not temperature-compensated in this unit. A calibration curve was established and conductivity values corrected with the use of simultaneous temperature data.

Light Penetration

Light penetration was routinely measured during the ice-free season with a Secchi disk. The disk used during the summer of 1973 was a 20-cm limnological style disk painted in alternating quadrants of black and white. During the remainder of the project, a 50-cm oceanographic style white disk was used.

Occasionally, light penetration was measured with a GM submarine photometer consisting of a matched set of Weston photocells encased under opal glass filters in a gimballed deck cell and a finned sea cell. The penetration of red, blue, and green light was measured by attaching the appropriate filters under the opal glass filter on the sea cell.

CHEMICAL LIMNOLOGY

Sampling

Samples for nutrient analysis were collected with a 4- or 6-liter Van Dorn sampler and, in a few cases, with a portable peristaltic sampling pump. Samples to be analyzed immediately, such as alkalinity, were placed in collapsible plastic cube-shaped containers while samples to be stored were placed in acid-washed plastic bottles and frozen.

Ammonia

Ammonia was determined by the automated phenol-hypochlorite method as outlined in the USEPA *Methods for Chemical Analysis of Water and Wastes* (1971). Reagent flow rates were reduced relative to sample flow to minimize dilution of the extremely low ammonia levels encountered in Harding Lake. At concentrations around the detection limit of 5 μg/l as nitrogen we encountered problems similar to those of scientists studying Lake Tahoe (Goldman, 1974). Contamination of the samples in the laboratory atmosphere was a serious problem demonstrated by the appearance of large spikes between samples. Efforts to eliminate this interference were largely unsuccessful. Clasby, R. C., (1974, personal communication) indicated that this problem was a persistent one in ammonia determinations at such low levels.

During the second year of the project, an attempt was made to determine ammonia at the new field station using a manual phenol-hypochlorite method (Environment Canada, date unknown). Ammonia analysis was terminated shortly thereafter as consistent values at or below the detection limit throughout an annual cycle were indicative of a low concentration situation in the lake and more detailed data did not warrant the time required for careful analysis (Alexander, V. A., 1974, personal communication).

The data which were obtained must be regarded as estimates, particularly where concentrations are reported at or below the detection limit of 5 μg/l. At such low levels, there is also the possibility of error from storage losses, even though these were minimized by analysis of fresh samples.

Reeburgh, W. S., (1974, personal communication) indicated the feasibility of trace ammonia analysis by stripping ammonia from a sample with an inert gas, after making the sample sufficiently basic to drive the equilibrium to free ammonia. The ammonia could then be trapped in a boric acid solution and concentration determined by a conductometric method using a differential conductivity cell. Such a method had not been standardized, however, and could not be developed by this project.

Organic Nitrogen and Ammonia

It had been intended to determine total Kjeldahl nitrogen and total phosphorus simultaneously, utilizing a Technicon Auto-Analyzer with a continuous digestion unit. Difficulties with the operation of the unit and especially poor results with total phosphorus resulted in termination of attempts to run the analyses by Kjeldahl digestion. Gales and Booth (1974) report excellent recoveries of both phosphorus and nitrogen by a vanadium pentoxide catalized digestion procedure. Personal communication with Gales, M. E. (1975) revealed problems in pH control of the phosphorus side of the determination which is highly dependent on acidity. The recommendation was to use a manual phosphorus digestion, using a Technicon continuous digestor if possible, and independent nitrogen determination.

Because of scheduling problems with the Technicon continuous digestion unit, it was decided that a manual organic nitrogen method would be used. The method for organic and ammonia nitrogen was taken from the USEPA methods manual (1971). In this procedure, organic nitrogen is manually digested with sulfuric acid and potassium persulfate, with subsequent determination of the resulting ammonium sulfate by the phenol-hypochlorite procedure utilizing the automated colorimeter.

Nitrite/Nitrate

Nitrate and nitrite were initially determined by the automated hydrazine reduction method (USEPA, 1971) which reduces nitrate to nitrite. The nitrite is then determined by diazotization with sulfanilamide and coupling with N-(1-napthyl)-ethylenediamine dihydrochloride to form a highly colored absorbing species. An alternate method, using a copper cadmium amalgam reduction column, was not initially used as prior experience with the system allowed us to be aware of the tendency of the column to plug and channelize. However, in 1975 the improved cadmium reduction method of Stainton (1974) was incorporated.

This method utilizes a 1-m length of cadmium wire jacketed in a length of Teflon tubing. This column is coiled and attached to the Auto-Analyzer manifold. The nitrite produced by the column is determined as in the hydrazine method.

The amalgamation and regeneration procedure for this column followed the recommendations of Clasby, R. C. (1975, personal communication). Ten ml of distilled/deionized water was alternated with 10 ml of 10% HCl, 10 ml of 2% $HgCl_2$, and 10 ml of EDTA, beginning and ending with a water rinse.

Phosphorus

Total phosphorus was determined by manual digestion according to the ammonium persulfate method and subsequent quantitation by the single reagent method (USEPA, 1971).

The digestion procedure followed the method published in *Methods for Chemical Analysis of Water and Wastes* (USEPA, 1971) with the addition of the neutralization step with phenolphthalein indicator. This procedure is similar to the more recent procedure (USEPA, 1974) which differs only in strength of the strong acid solution and utilizes a potentiometric (pH) neutralization. The single reagent method is unchanged in the 1974 mannual.

Some orthophosphate analyses were attempted initially in the project by the single reagent method (USEPA, 1971) and also by the extraction procedure of Shapiro (1973). As with many of the analyses, low levels resulted in difficulties in attaining reproducible results. It also became apparent from the literature (Rigler, 1964; Schindler, D. W., 1975, personal communication) that orthophosphate is difficult to determine and the results are often in question as to reliability and interpretation. As Vollenweider (1971) and others are utilizing total phosphorus in interpreting lake nutrient status, it was eventually decided to determine total phosphorus only.

Inorganic Carbon

Harding Lake itself contains negligible quantitites of humic material and other species contributing to alkalinity apart from the carbonate system. Alkalinity values were then taken to be representative of the inorganic carbon in the lake.

Alkalinity was initially determined by potentiometric (pH) titration with 0.02 N Sulfuric acid as outlined in Standard Methods for the Examination of Water (APHA, *et al.*, 1971) and graphical analysis of the end point. This procedure was later run at the same time as conductometric determination of the end point according to the method of the International Biological Programme (Golterman, 1969). The conductometric method was found to give a sharply defined equivalence point and was adopted.

Total Organic Carbon

At the outset of the project, total organic carbon was determined on a Beckman Carbonaceous Analyzer. Concentrations in Harding Lake were found to be near the detection limit of the instrument. Since the variability of the analysis was greater than that likely to occur in the lake, the analysis was discontinued.

BIOLOGICAL LIMNOLOGY

Algae

Direct Counts--

Samples for direct counts of plankton population were taken with a non-metallic Van Dorn sampler and each 100-ml sample was placed into a glass bottle containing 10 ml of Lugol's iodine. Upon reaching the laboratory, the sample bottles were thoroughly shaken and 5 ml from each sample was placed in a settling chamber and allowed to settle for approximately 24 hours.

Transects across the area of the counting chamber were examined using 400x magnification on an inverted microscope. Usually 1/4 of the chamber was examined, but 1/2 chamber was counted when low numbers were encountered.

Chlorophyll *a* and Phaeophytin--

Chlorophyll *a* content of the algae was determined according to the method delineated by Strickland and Parsons (1965). Approximately two liters of water were filtered through a glass-fiber filter under reduced light conditions and with the vacuum controlled at 15-20 cm of mercury. The filters were frozen until the extraction could be carried out. Phaeophytin was determined on acidified extracts according to the method presented in the IBP manual, *Chemical Analysis of Fresh Water* (Golterman, 1969).

Autotrophic Primary Productivity--

Algal primary productivity was measured in a light- and dark-bottle test following Goldman (1963) with the following modifications. The samples were taken with a nonmetallic Van Dorn sampler and distributed to two light bottles and one dark bottle for each depth. The dark bottles were prepared by dipping the typical borosilicate reagent bottles of approximately 125-ml size in black latex and taping with two layers of black electrical tape. The top of the ground glass stopper was treated in the same way and the cap and neck were covered with aluminum foil during incubation to exclude all light.

The bottles were each innoculated with 5 microcuries (μCi) of radioactive sodium bicarbonate NaH^*CO_3 and secured on their sides in plexiglass holders along a buoyed and anchored cord. In the winter the cord was suspended from a wooden dowel placed across the access hole and the hole was covered with materials opaque to light, usually snow. The incubation period was routinely 24 hours as had been recommended by Hobbie (1962). At the end of the incubation period each bottle was placed in an insulated light-tight box and filtration of either the whole bottle or a 50-ml aliquot was conducted as quickly as possible through a 2.5-cm diameter 0.45-μm membrane filter.

Filtration vacuum was controlled at 15-20 cm of mercury to prevent lysis of cells. All manipulation of the samples was carried out under reduced light conditions to prevent damage to light-sensitive cells. The filters were not dried but were immediately dropped into 10 ml of Aquasol, a liquid scintillation cocktail which dissolves the filter and is miscible with water. Drying of the filters was avoided in order to prevent autorespiration of labeled cell material which is a problem associated with slow death of labeled cells (Law, A. T., 1974, personal communication).

Counting was conducted in an ambient temperature liquid scintillation counter for three 10-minute periods for each vial. Corrections were made for quench and background. Calculations were performed based on those presented in the IBP manual on primary production (Vollenweider, 1969a).

Alkalinity, a measurement of the nonradioactive carbon (C-12) available to plants in the natural aquatic system, was measured for each depth at which productivity was measured.

During the first phase of the project, an attempt was made to measure algal productivity using the acidification-bubbling technique of Schindler, Schmidt, and Reid (1972). At the same time an attempt was made to modify the technique to allow the use of miniature scintillation vials to reduce the use of the expensive liquid scintillation cocktail. These two modifications were abandoned as being incompatible with the low productivity situation encountered.

Heterotrophic Production--

Heterotrophic production of the algae and bacteria was measured following the methods outlined in the paper by Maeda and Ichimura (1973). Numbered borosilicate bottles were filled with lake water taken from 3 m, and carbon-14 labeled glucose was added in triplicate at concentrations of 0.018, 0.036, 0.072, 0.144, and 0.288 mg/l. Other bottles were filled and triplicate treatments of carbon-14 labeled sodium acetate at concentrations of 0.00024, 0.00047, 0.00094, 0.00188, and 0.00376 mg/l were set up. One set of concentrations of each treatment was immediately killed with Lugol's iodine. A different set of all concentrations of each treatment was dosed with streptomycin at 3 mg/l. The bottles were incubated *in situ* for 21 hours well away from the access hole in the ice. A slit was cut with a 1.5-m ice saw and the rope suspending the incubation rack was moved from the access hole to the end of the slit and anchored. The hole and slit were covered with enough snow to exclude light. Filtration and counting were conducted in the same manner as for the algal primary productivity experiments.

Vascular Aquatic Plants

The beds of vascular aquatic plants were mapped by a skin diver who delineated the extent of the bed with a marked line. The water depth was measured at equally spaced intervals with a weighted, marked line by a person in a boat who was recording data.

At the height of the growing season stands that were noted to be pure (of only a single species) were sampled with either a $3.57 \times 10^{-1} m^2$ quadrat or a $5.29 \times 10^{-2} m^2$ Ponar dredge. The above-ground biomass was separated, dried and weighed, providing a biomass estimate for 100% cover of that species.

Transects were then laid out in the plant beds perpendicular to the shoreline and percent cover of each species was estimated by a diver for a $3.57 \times 10^{-1} m^2$ quadrat sample placed every 5 m from shore to the outer edge of the plant bed.

Zooplankton

Net Hauls--

Zooplankton were routinely sampled by 20-m vertical hauls with a small (76 cm long x 13 cm mouth diameter) Wisconsin net with a mesh size of 76 microns. The samples were washed into 20-ml glass vials with either distilled water or 90% ethanol (in winter). Upon return to the laboratory these vials were emptied into tared weighing pans and dried in a 60°C oven for 24 hours to a constant weight.

Traps--

Zooplankton were occasionally sampled with a clear plexiglass rectangular trap (0.074 m^3) lowered and raised by means of a winch. The trap has hinged doors at the top and bottom that swing open as the trap falls through the water column and close as the trap begins its return to the surface. A plankton bucket (158-micron mesh) is attached near the bottom of the trap so that the entire contents of the trap are filtered. The contents of the plankton bucket were washed into 300-ml polyethylene bottles with filtered lake water and 10 ml of Lugol's iodine solution were added. In the laboratory, ten 1-ml subsamples were taken with a Hensen-Stempfle pipette and all fields were counted in a Sedgewick-Rafter counting cell.

Benthic Macroinvertebrates

Sampling was accomplished with a standard 15.24-cm square Ekman dredge. Each sample was immediately washed free of sediments in a #30 mesh (590 micron) screen-bottomed bucket, and the remaining contents were washed into a 1.14-liter jar. Alcohol was added to bring the concentration to approximately 25% by volume and the samples were returned to the laboratory where they were refrigerated at 5°C until the organisms were picked.

Picking was accomplished on the entire sample by diluting subsamples in white enamel pans and separating the organisms from the debris with forceps. The organisms were separated to order and stored in 90% ethanol until identified.

Chironomid larvae from the 1973 samples were prepared for identification by preparing head capsule mounts on glass slides. Each chironomid so prepared was heated in 5% KOH for fifteen minutes (or immersed overnight in cold KOH) and rinsed in distilled water, then the head was dissected onto a glass slide and covered with a water-miscible mounting medium. After checking that the head was in position with teeth uppermost, a cover slip and label were affixed. The body was left on the slide if it were sufficiently small and flattened.

The samples for the rearing effort were taken with a standard Ponar dredge or by hand and treated as above except that ethanol was not added to the quart jars. Picking was accomplished almost immediately at the field laboratory located at the lake. Each chironomid larva or pupa was placed in a separate 10-ml vial with clean lake water and the vial was plugged with cotton.

Daily checks were conducted on all vials so that the adults and associated ecdyses could be preserved. As soon as an adult was observed in a vial, the vial was placed in an ethyl acetate killing jar, when the cotton could be removed 90% ethanol was added, and a screw cap affixed. The dissected adults and associated ecdyses were later mounted and identified.

Enteric Bacteria

All bacteriological analyses (standard plate counts, total coliform, and fecal coliform) were performed by the Fairbanks laboratory of the Alaska

Department of Health and Social Services. The state laboratory follows the bacteriological procedures set forth in the 13th edition of *Standard Methods for the Examination of Water and Wastewater* (APHA, *et al.*, 1971). Samples were collected in sterilized glass and plastic containers supplied by the laboratory. All samples, with the exception of vertical distribution samples, were collected at the water surface and were taken from the bow of a slowly moving boat. Samples were stored in insulated containers containing ice prior to and during transport to the state laboratory. Storage time for the samples ranged from 5 to 23 hours and it is noted that the recommended storage time is 8 hours or less (APHA, *et al.*, 1971). Vertical bacteriological profile samples were obtained by using a Van Dorn water sampler.

SECTION 6

RESULTS AND DISCUSSION

CLIMATOLOGY

Heat Budget

From the thermal data taken, it was possible to estimate the heat budgets of Harding Lake for three years (1973, 1974 and 1975). The calculated heat budgets include the energy required to heat the water in the lake from the minimum temperature to the maximum temperature, and the amount of energy needed to melt all ice on the lake. The energy required to heat the ice from its minimum temperature to the melting point is comparatively small and was not calculated.

TABLE 1. HEAT BUDGET ESTIMATES FOR HARDING LAKE--1973-1975

Year	Ice thickness (cm)	Heat needed to melt ice (cal/cm^2)	Winter heat* income (cal/cm^2)	Summer heat** income (cal/cm^2)	Annual heat budget (cal/cm^2)
1973	81	5,941	8,991	8,700	17,691
1974	100	7,309	10,819	10,196	21,015
1975	77	5,612	9,292	10,770	20,062

*winter heat income is that amount of heat necessary to melt the ice and heat all lake water to 4°C.

**summer heat income is that amount of heat necessary to raise the water temperature from 4°C to its maximum.

In the heat budget calculations, the total area of the lake was taken to be 9.9×10^{10} cm^2; this, of course, varied slightly with the water level during a given year.

A thermal regime of a shallow (3m) arctic lake (Imikpuk Lake, 70°N) at Barrow, Alaska, reported by Brewer (1958) gives an approximate annual heat budget of around 14,000 cal/cm^2 of which 90% is accounted for by ice cover. This occurs in an area having a thawing index of about 500 degree days compared with 3000 degree days for Harding Lake.

A deep arctic lake (Schrader Lake 69°N) has a summer heat budget of approximately 9000 cal/cm^2 (Hobbie, 1973). No winter heat budgets are reported but ice thicknesses are somewhat greater than Harding which would put its annual heat budget somewhat above Harding. Since the thermocline of Schrader is deeper, the maximum summer temperature generally runs half that of Harding and in some years remains near 4°C when statification is not set up. Thus Schrader Lake cannot be considered temperate, while Harding Lake fits Hutchinson's (1957) definition of a temperate lake.

Hydrology

In order to obtain a rough water balance for Harding Lake, climatological data was collected throughout the study and intensively during the summer of 1974. As a result of these measurements, the following estimates of water input to the lake were made for June 1974 to June 1975 (given in terms of change in lake level):

1. Direct rainfall on lake = 16.5 cm (6.5")
2. Rainfall runoff to lake from immediate drainage area = 1.5 cm (0.6")
3. Snowmelt on lake = 13.0 cm (5.1")
4. Snowmelt runoff to lake from immediate drainage area = 6.6 cm (2.6")
5. Input from stream at northeast end = 2.8 cm (1.1")

From the above, it is estimated that the annual total lake input is about 41 cm. Evaporation was calculated from pan measurements to be about 18 cm, and since the lake level did not change appreciably, there must be a net groundwater loss of about 23 cm.

An adjoining drainage basin east of Harding Lake of about 2600 hectares provides some input to the lake (Figure 3). However, this stream is divergent and splits into two streams about 3 km from the lake. From streamgaging measurements, it appears that during times of high streamflow such as the snowmelt period, about 30% of the flow goes to Harding Lake and 70% to the Salcha River. During periods of low flow only approximately 10% flows into the lake.

Base flow of the stream during the summer seemed to be about .07 m^3/sec while the peak measured during the snowmelt period was slightly over .6 m^3/sec. The stream has apparently been divergent for some time, since channel formation is fairly mature for both the divergent branches. The older channel is probably the one to the lake, but this is by no means certain.

It appears that it would be possible to control the lake level somewhat by diverting more of the flow of the stream toward the lake during natural periods of low lake level, but further studies would certainly be needed to assess the total amount of available streamflow, the type of diversion apparatus needed, and most importantly, the ideal lake level. From streamflow measurements, it was estimated that if all available water had gone to Harding Lake during 1975, the lake level would have been raised by over 10 cm. However, the water available in the stream probably is highly variable from year to year.

PHYSICAL LIMNOLOGY

Thermal Regime

Figure 4 illustrates slightly more than two annual cycles of the temperature regime of Harding Lake. From this graph it could be inferred that Harding Lake is dimictic, undergoing a complete mix top to bottom in both autumn and spring. While this is undoubtedly true for most years, much evidence was seen for the possibility of an incomplete turnover in the spring of occasional years. During the late spring of 1974 while the lake was still almost completely ice covered the field crew noted water considerably warmer than 4°C close to the lower surface of the ice, though this seemed to consist of a very thin layer easily disturbed by the probe assembly

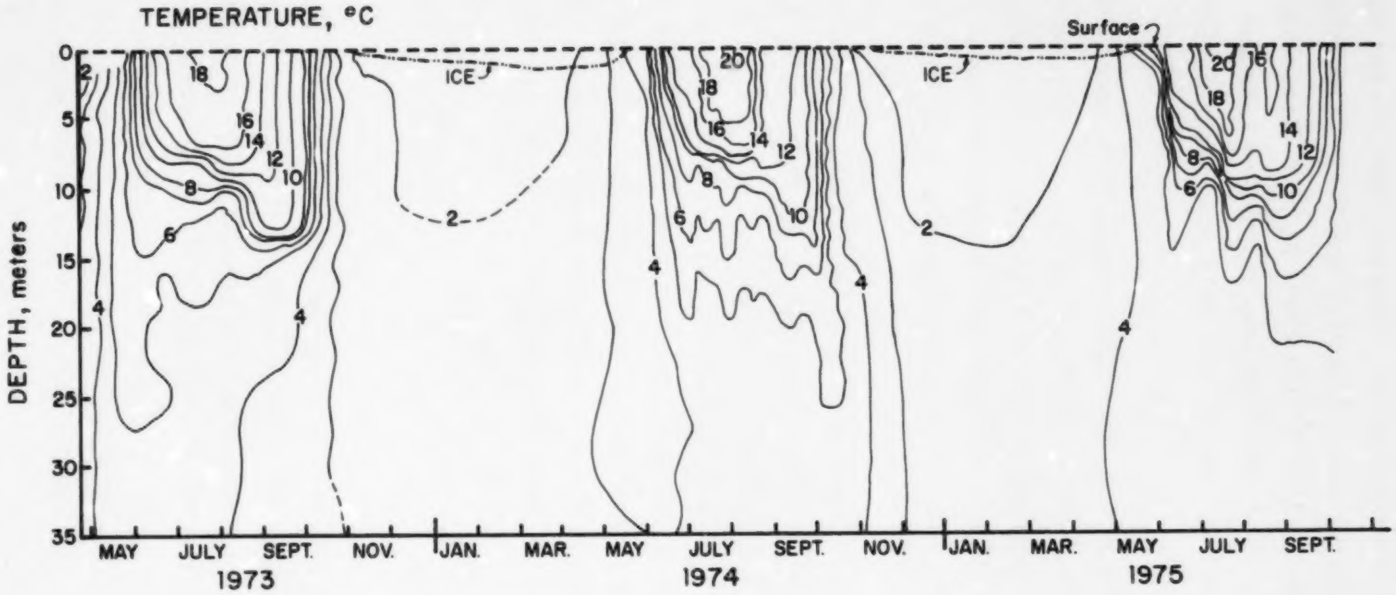


FIGURE 4

ISOTHERMS-HARDING LAKE, WITH ICE THICKNESS INDICATED of the Martek Mark II. The existence of warm layers beneath melting ice was attributed to flow of meltwater under the ice by Hutchinson (1957). This water is less dense even at 4°C than the water below because of low salt content.

The ice at that time was noted to be candled, that is, with long vertical holes throughout the structure. A good discussion of ice-melting phenomena for arctic lakes, which describes thoroughly the process at Harding Lake, is contained in a review paper by Hobbie (1973). On May 31 the ice was observed to cover approximately 67% of the lake surface; a wind arose that night and the lake was essentially ice free on June 1. This is a frequently observed phenomenon attributable to ice candling, a condition wherein the ice cover is composed of loosely packed ice candles. These may be tipped easily by the wind and then are rapidly melted by the warmer water. The weather remained windy through June 2 when our field crew observed..."heavy waves, fetching towards the NE shore, approximately 6 m long and up to .6 m in height." On that day, measurements of various parameters showed the lake to be in full wind-driven overturn.

During the next winter a set of thermistors was attached to a wooden post and frozen into the ice in such a position that the thermistors were spaced every 0.15 m throughout the ice and water column to 1.8 m. Heavy snowfall caused depression of the ice allowing water to seep up within the snow and when the latter froze, the thermistor cords, though bagged together and tied high on the pole, froze into the ice. On May 9, 1976, the entire pole had melted free of the surrounding ice and was removed. It was observed that anything of different albedo than the ice, even a piece of white cardboard box lying on the ice, would melt down into the ice as radiation was absorbed.

On May 9 and May 21, a thermistor was lowered gently down a 0.15 m hole which had been drilled with a power ice auger and left undisturbed for at least a day. Figure 5 illustrates the results found. In both cases the water was being warmed by solar radiation, and by May 21, this heating was dramatic. The ice was entirely gone by May 27, and, on May 29, measurements showed the lake to be weakly stratified. The reappearance of the 4°C isotherm while the ice was still on the lake followed by slowly strengthening

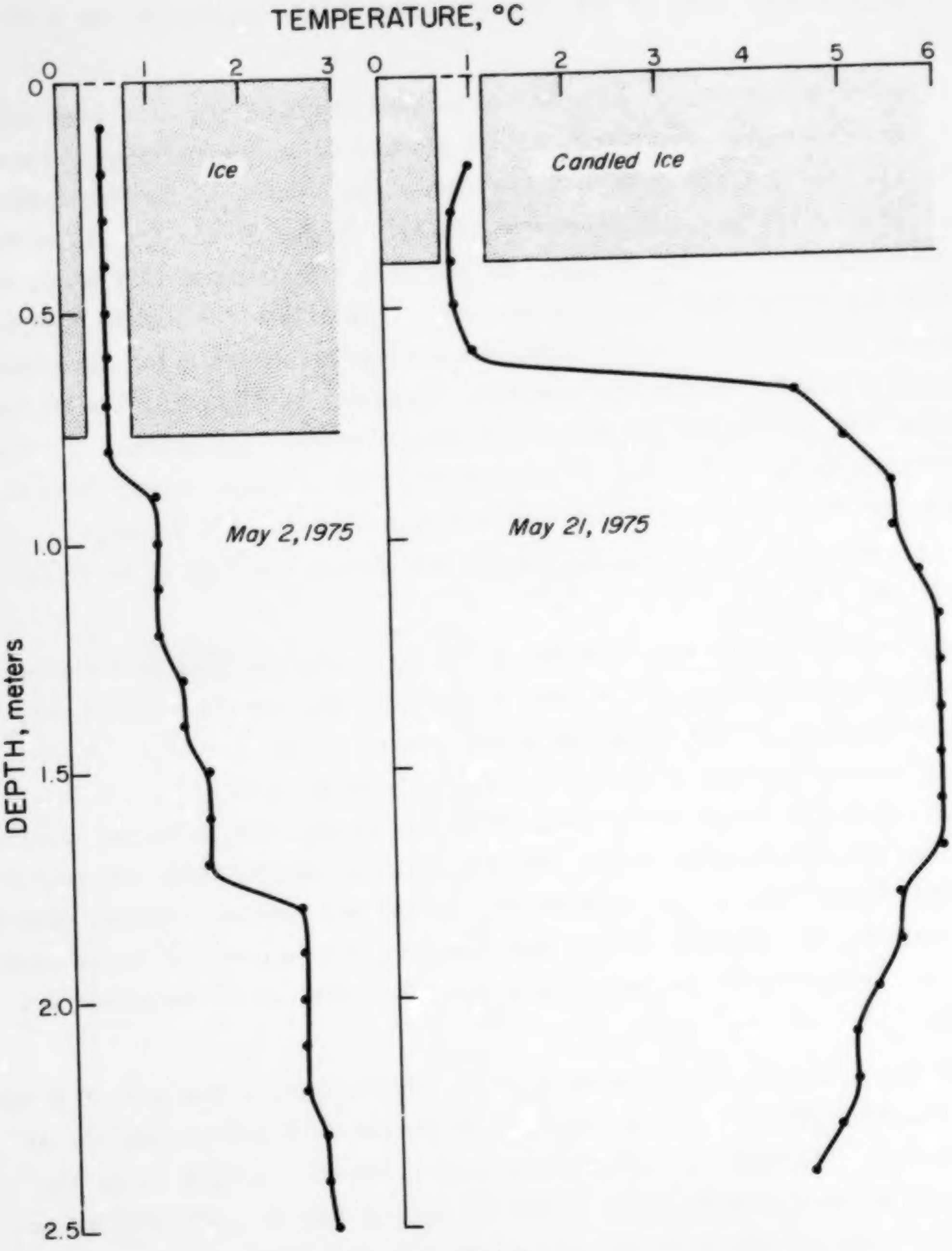


FIGURE 5
TEMPERATURES OBSERVED UNDER ICE AT HARDING LAKE, MAY 1975

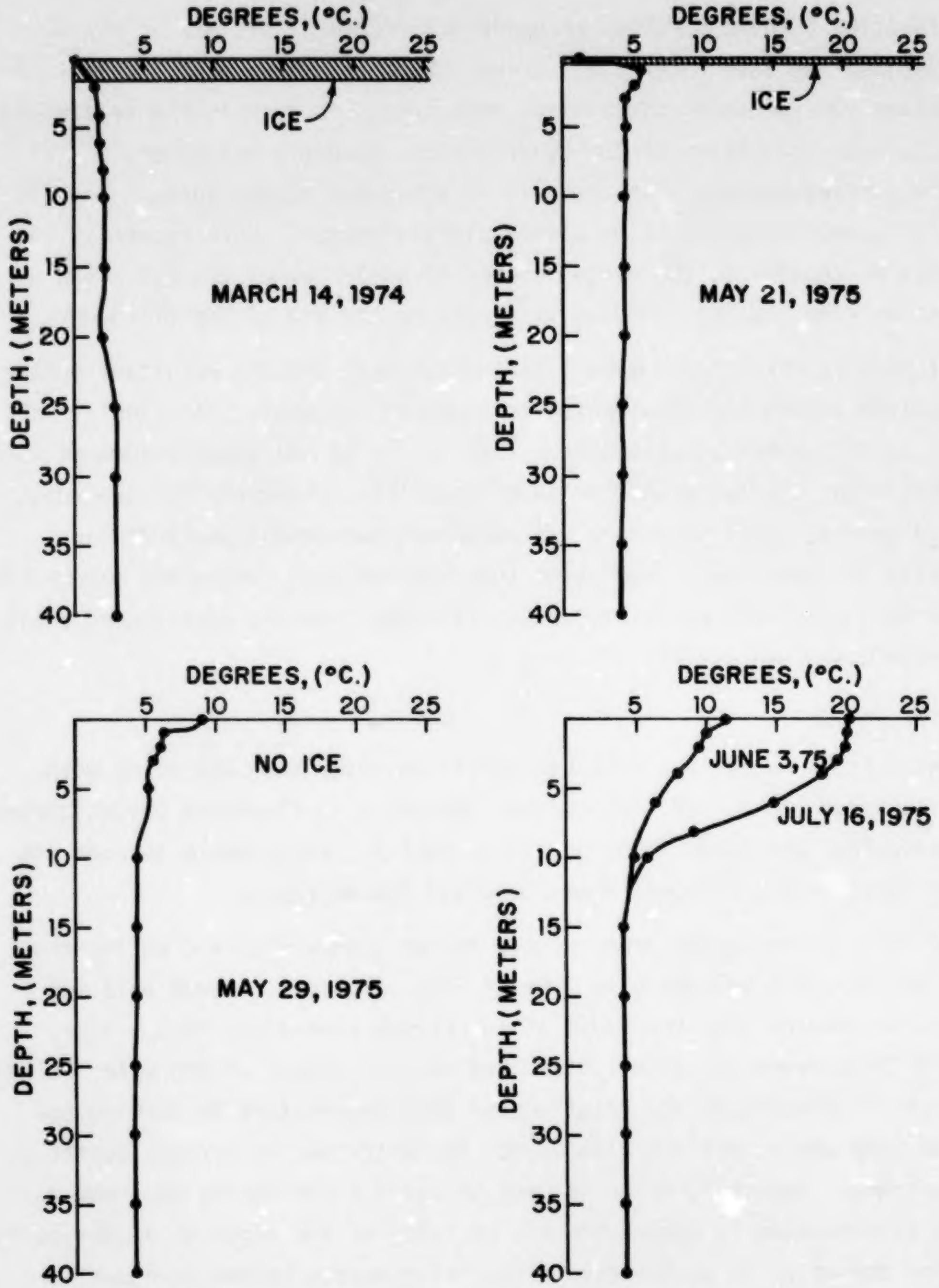


FIGURE 6

TEMPERATURE PROFILES FOR SELECTED DATES. SPRING 1975, HARDING LAKE stratification (Figure 6) shows an under-ice overturn that may or may not have involved the deep water that spring. Further evidence of the lack of wind-driven reoxygenating circulation that spring is seen in Figure 7 where it can be seen that water of low conductivity, probably meltwater, stayed near the surface unmixed with the rest of the water column through ice-off and until summer stratification was completely formed. Unfortunately, the necessity of repairs to the Martek system in early summer did not allow us to get data to complete this conductivity plot to the end of the field work.

If Harding Lake should miss a spring turnover and the resultant uptake of dissolved oxygen the hypolimnion is expected to remain sufficiently well oxygenated to support aquatic life. This is due to the great volume of the hypolimnion and the low productivity of this lake. However, for subarctic lakes in general, this potential has important management implications, especially for lakes more productive than Harding Lake, where the decomposition of dead plant and animal materials settling into the hypolimnion could use up the dissolved oxygen.

Dissolved Oxygen

While it is recognized that biological activity has much to do with dissolved oxygen in a lake, the primary influence on dissolved oxygen content in Harding Lake was found to be physical, that is, explainable through the inverse relationship between temperature and concentration.

Failure of the oxygen probe of the Martek system occurred during the winter of 1973-1974 and again in June of 1975. However, enough data was obtained to provide some knowledge of the oxygen conditions in the lake. Figure 8 illustrates the actual dissolved oxygen content of the water column and Figure 9 illustrates the relationship with temperature by showing how close to complete saturation with oxygen the water was at various depths at various times. Supersaturation is seen at about 6-8 m during the summers. This is attributable to photosynthetic activity of the algae at depths sufficient for the water to be isolated from mixing except by the strongest winds.

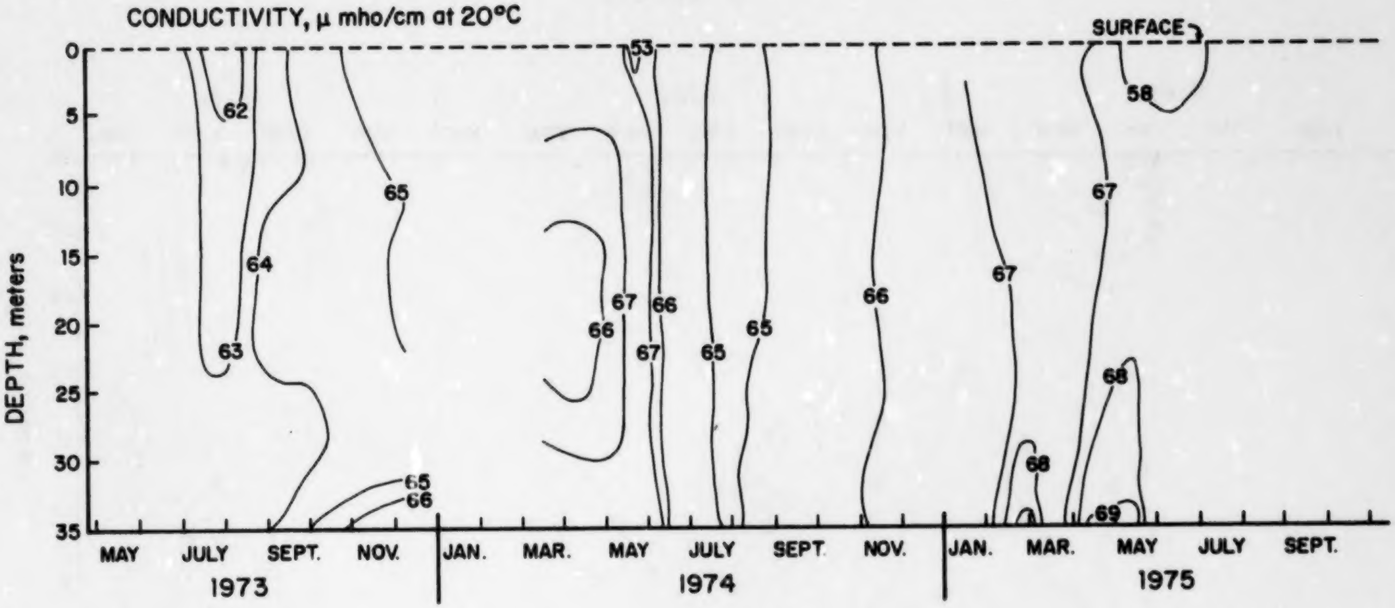


FIGURE 7

ISOPLETHS OF ELECTRICAL CONDUCTIVITY. HARDING LAKE

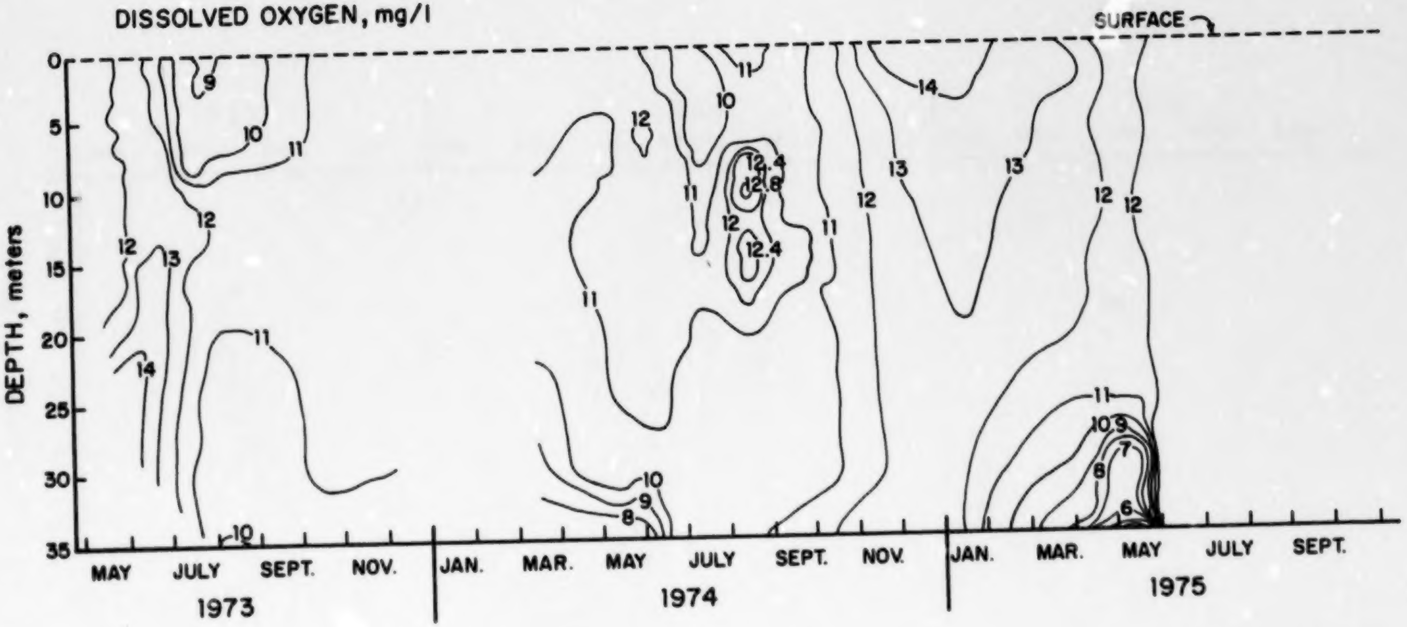


FIGURE 8

ISOPLETHS OF DISSOLVED OXYGEN. HARDING LAKE

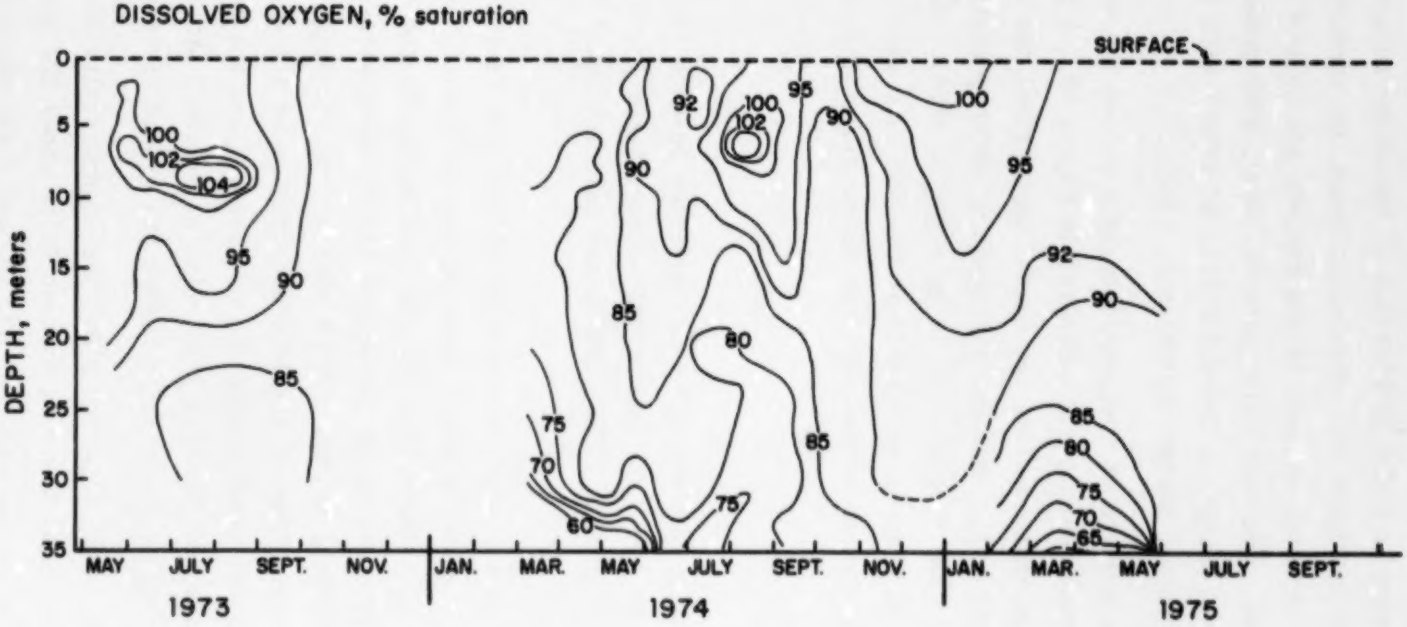


FIGURE 9
ISOPLETHS OF PERCENT SATURATION OF DISSOLVED OXYGEN. HARDING LAKE

Light Penetration

The characteristics of light penetration of the water column on June 26 1975, are illustrated in Figure 10. This measurement was conducted on other occasions during the ice-free seasons of the project and no significant differences were noted. The particular pattern shown, with green light penetrating to greatest depth, is characteristic of waters with a small amount of dissolved organic matter (Hutchinson, 1957).

Secchi depths were taken at frequent intervals during the ice-free season, and these measurements are illustrated in Figure 17. A commonly used "rule of thumb" states that doubling the Secchi depth gives the compensation depth for algal productivity, that is, the depth at which photosynthesis equals respiration and net productivity is zero (Cole, 1974). Examination of Figure 17 shows this rule to be applicable to Harding Lake with some occasions when net productivity stopped either above or below double the Secchi depth.

CHEMICAL LIMNOLOGY

Ionic Composition

The water quality parameters and a cation/anion balance for Harding Lake have been determined by the U. S. Geological Survey, Table 2. Other analyses have been reported by Barsdate (1966, 1967), and selected data is presented in Tables 3 and 4.

Of significance to the ionic composition of the lake is the small area of the drainage basin, which is about equal to the surface of the lake itself. The lake is in a transition zone between muskeg to the north and steep hills covered with deciduous (aspen and birch) and coniferous (spruce) forest on the other compass points. Since most of the drainage is rapid from the slopes, the residence time of liquid precipitation on the ground is short. Also reducing potential weathering of minerals are the extended period of frozen ground and the high proportion of snowfall which is rapidly lost through sublimation or evaporation before the ground is thawed.

Data of Barsdate (1966) show the electrical conductivity of Birch Lake, a lake of the same formation group as Harding to be about 50% greater than that of Harding. Relative abundance of Mg, Ca, and K are approximately

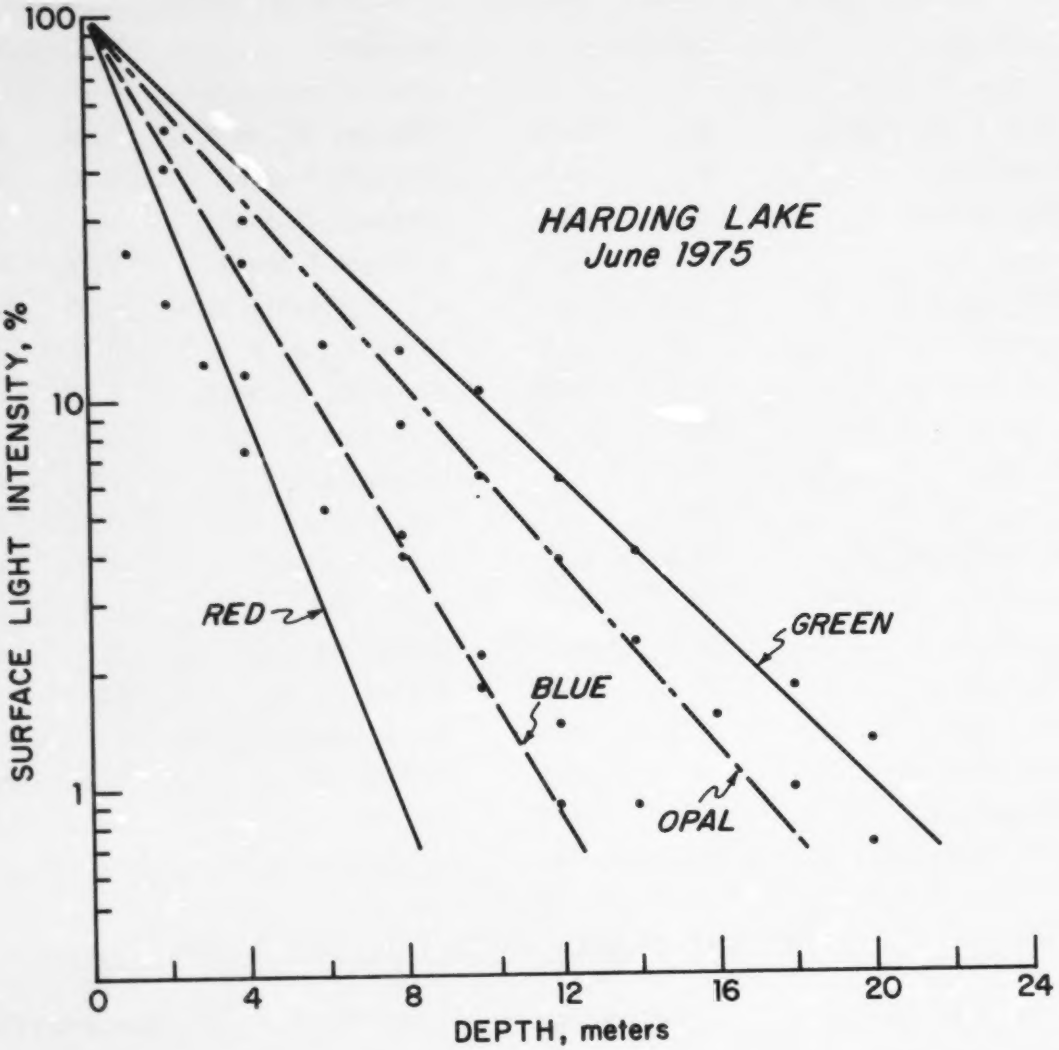


FIGURE 10

LIGHT PENETRATION. HARDING LAKE

TABLE 2A. WATER QUALITY, HARDING LAKE, JUNE 3, 1975 (PROVISIONAL) (USGS)

Parameter	Concentration	
Alk, T (as $CaCO_3$)	30	mg/l
Aluminum T	50	μg/l
Bicarbonate	36	mg/l
Boron T	40	μg/l
Calcium dis	6.9	mg/l
Carbon T org	3.7	mg/l
Chloride dis	0.7	mg/l
Cobalt T	<50	μg/l
Color	7	
Copper T	30	μg/l
Fluoride dis	0.1	mg/l
Hardness, noncarb.	0	mg/l
Hardness, T	27	mg/l
Iron dis	10	μg/l
Magnesium dis	2.3	mg/l
Manganese dis	0	μg/l
Molybdenum T	0	μg/l

TABLE 2A. CONTINUED

Parameter	Concentration	
Nitrogen NH_4 as N T	0.04	mg/l
Nitrogen T as N	0.35	mg/l
Nitrogen T as NO_3	1.6	mg/l
Nitrogen T org N	0.26	mg/l
N (T Kjeldahl) as N	0.30	mg/l
NO_2 + NO_3 as N T	0.05	mg/l
NO_2 + NO_3 as N dis	0.05	mg/l
Orthophos dis as P	0.01	mg/l
Orthophos dis	0.03	mg/l
Phosphorus T as P	0.01	mg/l
Potassium dis	0.9	mg/l
Silica dis	0.3	mg/l
Sodium dis	1.5	mg/l
Sodium	11%	
Sp. Conductance lab	70	
Sulfate dis	3.1	mg/l
Zinc T	0	μg/l

TABLE 2B. CATION AND ANION BALANCE, HARDING LAKE, JUNE 3, 1975 (USGS)

Cations	Concentration		Anions	Concentration	
	(mg/l)	(meq/l)		(mg/l)	(meq/l)
Calcium dis	6.9	0.345	Bicarbonate	36	0.591
Magnesium dis	2.3	0.190	Chloride dis	0.7	0.020
Potassium dis	0.9	0.024	Fluoride dis	0.1	0.006
Sodium dis	1.5	0.066	Sulfate dis	3.1	0.065
			NO_2 + NO_3 as N	0.05	0.004
	Total	0.625		Total	0.686

TABLE 3. LIMNOLOGICAL PROPERTIES OF HARDING LAKE, 1966. (BARSDATE, 1967)

Date	Sample	Depth (m)	Temp. (C°)	Conductivity (μmho/cm, 25°)	D.O. (mg/l)	O. Sat. (%)	pH	Total Alk. (mg/l $CaCO_3$)	Water Color (Pt units)	Particulate Matter (mg/l)	SiO_4-Si (μg-A/l)	PO_4-P (μg-A/l)	NO_3-N (μg-A/l)
31 Mar	149	0.8	0.4	75	11.6	80	7.31	33	15				
	150	5	2.8	69	10.6	78	7.26	31	21				
	151	10	3.1	69	10.3	76	7.27	30	18				
	152	25	3.5	70	8.7	65	7.14	31	18				
30 Apr	164	0.8	0.0	81	12.5	86	7.45	36	30	0.0	23	0.00	2.6
	165	5	2.8	99	10.4	77	7.10	27	23	0.1	5	0.00	2.6
	166	10	3.1	80	10.2	76	6.63	19	23	0.0	16	0.00	2.0
	167	25	3.4	60	8.3	62	6.88	26	23	0.1	21	0.13	2.9
	168	42	3.7	96	0.2	2	6.89	37	50	2.4	55	0.10	1.1
2 Jun	189	0	4.8	48			7.53	19	21	0.3	13	0.00	0.2
	190	1	4.4	53	10.8	84	7.53	21	29	0.6	23	0.10	0.0
	191	5	4.1	69	10.2	78	7.45	26	30	0.3			
	192	10	3.7	74	10.2	77	6.82	20			10	0.10	1.2
	193	25	3.4	70	9.6	72	7.35	28					
	194	29		71	7.4	56	7.28	27	31	0.1	23		2.6
10 Jul	225	0	17.3	62	8.6	89	7.50	26	33	0.3	14	0.00	0.3
	226	5	16.4	64	8.8	89	7.35	24	32	0.2	11	0.00	0.2
	227	10	5.9	67	10.4	85	7.00	18	31	1.1	16	0.00	0.3
	228	25	3.7	66	8.4	64	7.10	24	35	0.3	24		2.9

(continued)

TABLE 3 (continued)

Date	Sample	Depth (m)	Temp. (C°)	Conductivity (μmho/cm, 25°)	D.O. (mg/l)	O. Sat. (%)	pH	Total Alk. (mg/l $CaCO_3$)	Water Color (Pt units)	Particulate Matter (mg/l)	SiO_4-Si (μg-A/l)	PO_4-P (μg-A/l)	NO_3-N (μg-A/l)
18 Jul	232	0	18.4	62	9.1	96	7.68	25	31	0.4	14	0.10	0.2
	233	5	18.4	66	9.0	95	7.68	25	32	0.3	15	0.03	0.2
	234	10	9.4	61	10.6	92	7.36	26	32	0.5	14	0.03	0.4
	235	25	4.0	66	8.8	67	7.11	29	33	0.1	26	0.03	3.1
	236	45	4.0	74	3.3	25	6.96	31	185	1.0	44	0.00	6.2
11 Oct	276	0	6.3	69	10.2	82	7.18	26	31	0.5			
	277	10	6.3	69	10.3	83	7.18	26	30	0.3			

TABLE 4. CHEMISTRY OF SNOW, ICE, AND WATER. HARDING LAKE. (BARSDATE, 1967)

Date	Sample No.		Thickness (cm)	Conductivity (μmho/cm, 25°C)	Alkalinity (mg/l $CaCO_3$)	Water Color (Pt units)	Particulate Matter (mg/l)	SiO_4-Si (μg-A/l)	PO_4-P (μg-A/l)	NO_3-N (μg-A/l)
April 30, 1966	169	Snow	8	5.2		0	10.3	0	0	0.7
"	170	Ice	~4			0	3.8	3	0.4	0.4
"	163	Overflow	~3	118	44	33	0.0	20	0.1	2.9
"	172	Overflow Ice	11	11	11	0	0.7	>1	0.2	0.4
"	173	Clear Ice	48			0	0.2	0	0.1	0.3
"	164	Lake Water		81	36	30	0.0	23	0.0	2.6
June 2, 1966	195	Residual Ice	20	9.8	4.8	9	1.7	27	0.0	0.2

(continued)

TABLE 4. (continued)

Date	Sample No.	Concentration (μg/l)						
		Copper		Manganese		Iron		Zinc
		Filtered	Total	Filtered	Total	Filtered	Total	Total
April 30, 1966	169	1.5	1.9	1.8	6.9	11	365	4.1
"	170	2.0	3.2	1.9	4.4	16	115	11
"	163	2.3	1.4	3.9	3.7	19	25	1.7
"	172	3.1	3.5	7.8	3.6	27	69	7.1
"	173	4.7	5.3	2.0	2.1	7.4	22	17
"	164	1.7	2.4	1.4	1.8	12	27	3.8
June 2, 1966	195	1.7	2.0	5.2	5.9	4.8	36	4.3

equal. This might be expected from the common geologic settings of the lakes, but actual concentrations are 2 to 3 times greater for these elements in Birch which has a substantially larger, flatter drainage. This is significant to the relative oligotrophy of Harding as it applies to nutrient loading in a comparable manner.

The ionic composition of the lake is bicarbonate type of moderate hardness. A comparison of the cationic composition to the average composition of the world rivers (Clark, 1924) shows the Mg/Ca ratio to be somewhat higher but not unusually so. Hutchinson (1957) points out that the composition of open lakes approximates the average river composition due to source materials and exchange reactions.

TABLE 5. CATION COMPOSITION OF WORLD RIVERS VS. HARDING LAKE

	Mean river concentration (%)	Harding Lake concentration (%)
Ca	63.5	55.5
Mg	17.4	30.5
K	3.4	3.8
Na	15.7	10.6

The reported compositions are consistent with the geology of the Yukon-Tanana Upland. These low-lying hills are covered with wind-blown loess composed of quartz, feldspar, and mica, particularly on slopes with a southern aspect. The bedrock, exposed in some areas, consists of granitic material and Birch Creek Schist, a quartz-mica schist. These silicaceous materials are relatively inert to weathering and dissolution, contributing relatively small amounts of calcium and bicarbonate to the lake compared to the potential contributions of limestone and other carbonate formations found in other areas of Alaska.

Hydrogen Ion Concentration

The results of our measurements of hydrogen ion concentration, as the negative logarithm, pH, are shown in Figure 11. Failure of the reference electrode during two periods of the field work of this project cause the patterns of fall and early winter to remain unknown. The 6.6 and 6.8 lines which appear only at the beginning of the project may be an artifact due to the initial use of a pH meter which is not thermally compensated on samples taken from a Van Dorn sampler. This was necessary while the Martek multiprobe system was being refitted for the work on this lake with a longer cord and a more sensitive electroconductivity transducer.

The patterns shown are typical for a lake of moderate alkalinity where the carbonate system buffers against any major changes. Slightly increased pH is seen near the surface during the height of the plant-growing season, as expected.

Nutrient Chemistry

Carbon--

Inorganic carbon was routinely measured as bicarbonate alkalinity as part of the procedure of measuring algal primary productivity. Alkalinity values ranged between 11.8 and 42.3 mg/l as $CaCO_3$, averaging 31.0 ± 3.5 mg/l. Bicarbonate alkalinity values were converted to the concentration of carbon present by means of the table of Saunders, Trama, and Bachmann (1962) which corrects for *in situ* temperature and pH differences. On at least two occasions, paired samples were both titrated for alkalinity and analyzed for dissolved inorganic carbon in a Fisher-Hamilton gas partitioner (chromatograph) according to the method of Stainton (1973) and the results were identical. Thus it was concluded that alkalinity provided an adequate measure of inorganic carbon. As was mentioned in the Methods section, organic carbon was measured on initial samples and then this measurement was abandoned as the Harding Lake samples varied little, remaining near 5 mg/l the detection limit of the instrument.

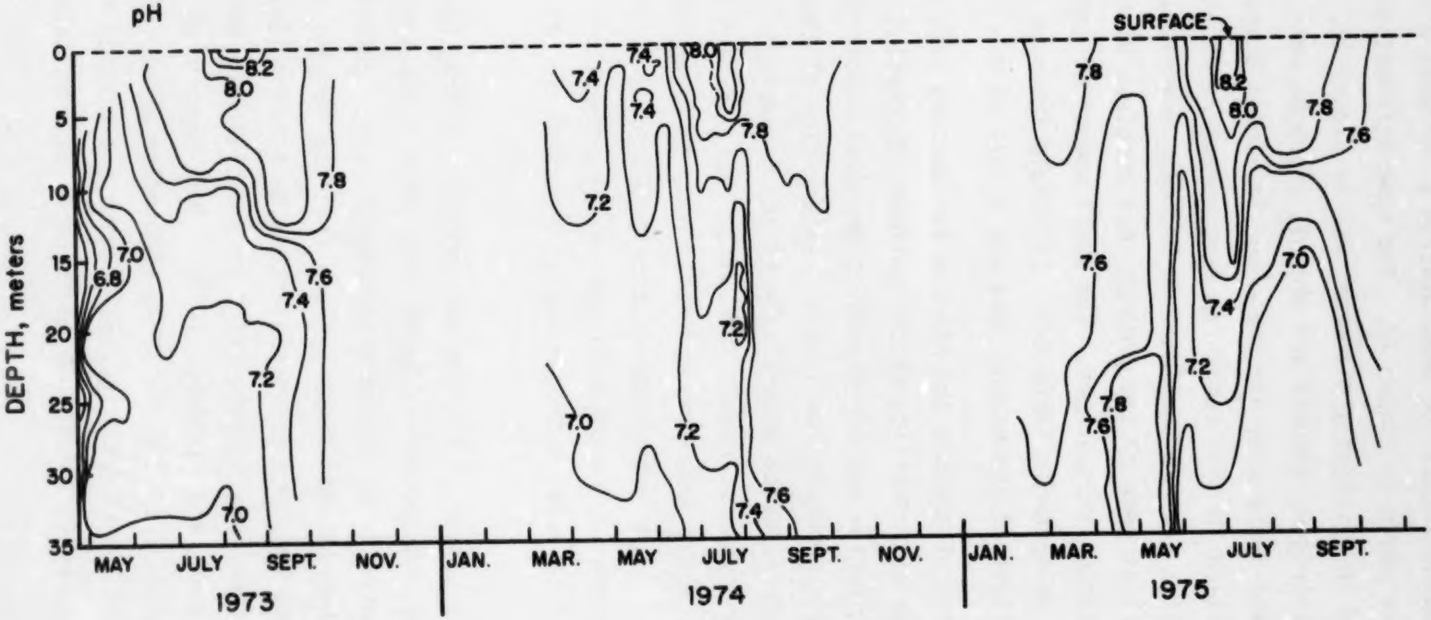


FIGURE 11

ISOPLETHS OF HYDROGEN ION CONCENTRATION AS THE NEGATIVE LOGARITHM, pH. HARDING LAKE

Nitrogen--

Nitrate/nitrite measurements for Deep Station I for most of the first year of the project are shown in Figure 12. The same information for most of 1975 is illustrated in a slightly different way in Figure 13. The remaining species of nitrogen, ammonia and organic nitrogen were measured together during 1975 and these data are presented in Tables 6 and 7 since there was little variation in this composite measurement rendering graphical illustration unnecessary. As was mentioned in Methods, ammonia was measured by itself during the first year of the project, but problems with contamination caused us to abandon this effort. The small amount of ammonia data obtained is presented in Appendix Table A-1. It should again be noted that the stated detection limit of the method used was 5 μg/l as N.

The nutrient cycles of ammonia and nitrate for Harding Lake display a vernal decline to below detectability which continues throughout the summer. Onset of autumnal circulation and corresponding physical conditions restores these nutrients to their predepletion levels. Observation of this type of cycle are common and are reported extensively in the literature for both marine and limnological systems (Steele and Baird, 1961; Stewart and Markello 1974; Lueschow *et al.*, 1970; Gruending and Malanchuk, 1974; and Schindler and Nighswander, 1970). This phenomenon is attributed to assimilation by bacteria and phytoplankton at the onset of the vernal production and subsequent mineralization of cellular nitrogen during autumnal die-off and decline in production.

In terms of concentration of nitrate and ammonia, Harding Lake is very similar in both cycling and concentration to Lake Tahoe (Lake Tahoe Area Council, 1971), considered to be a hyperoligotrophic lake. Unfortunately, most of the work on other Alaskan lakes is such that the results do not lend well to comparison since many are reconnaissance-type studies (Barsdate and Alexander, 1971; LaPerriere and Casper, 1976) or are obviously not morphologically comparable (Alexander and Barsdate, 1971). Some reports on lakes in the arctic, such as Char Lake, (72°42'N, 94°50'W) (Schindler *et al.*, 1974) or Lake Peters (69°19'N, 145°03'W) (Hobbie, 1962) which are clearly oligotrophic, show inorganic nitrogen levels comparable to those of Harding Lake.

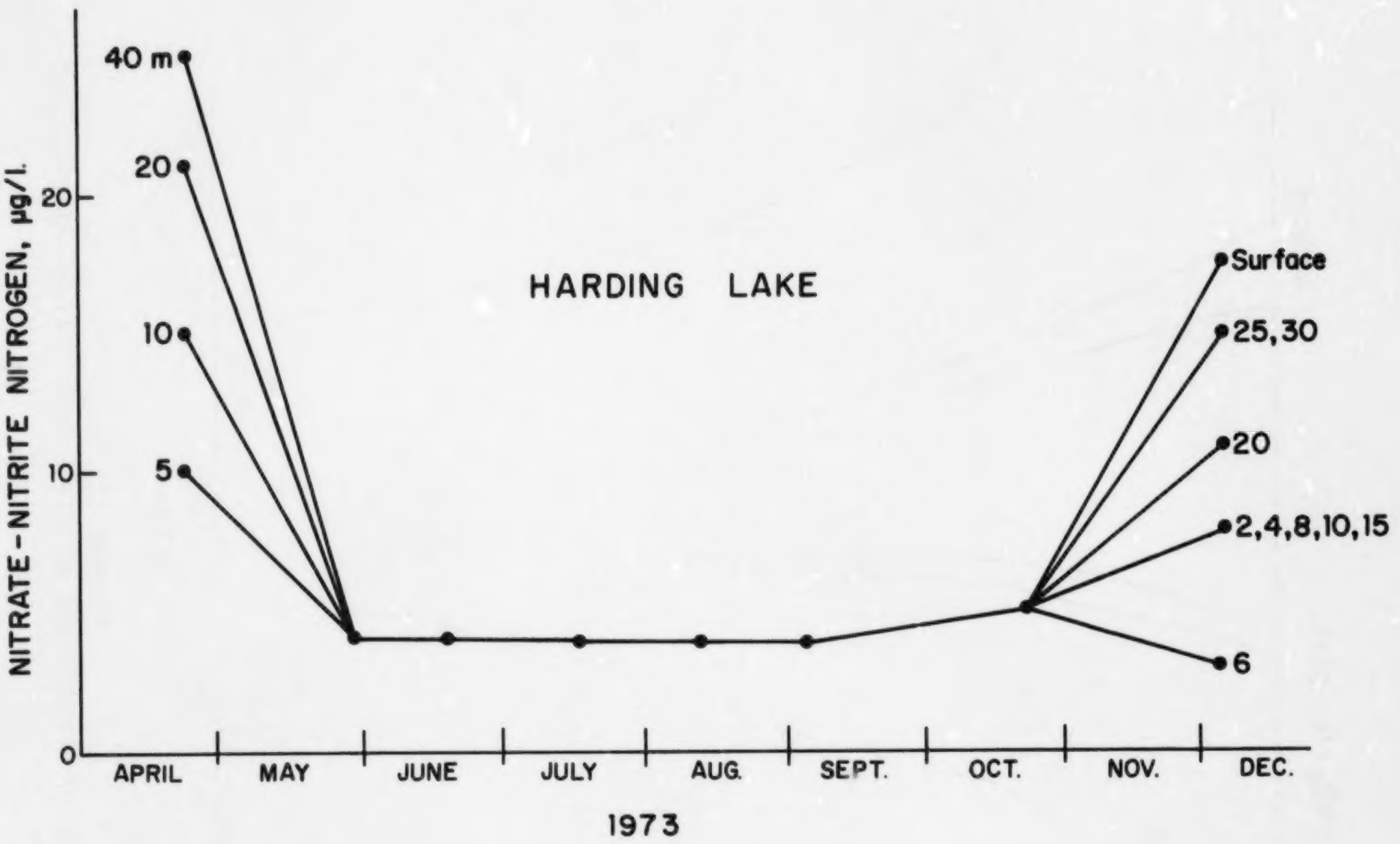


FIGURE 12
ISOBATHS - NITRATE AND NITRITE NITROGEN. HARDING LAKE

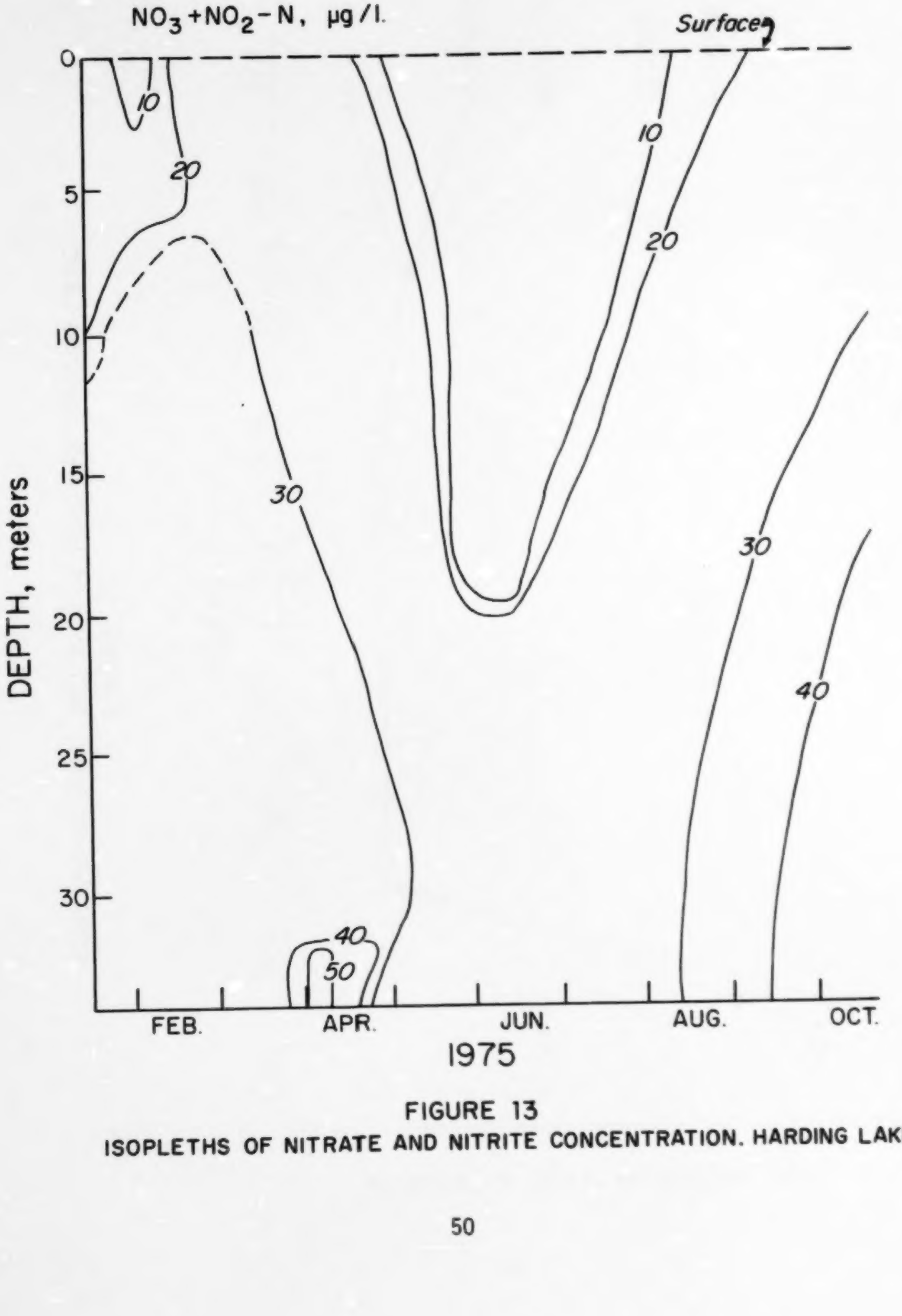


FIGURE 13
ISOPLETHS OF NITRATE AND NITRITE CONCENTRATION. HARDING LAKE

TABLE 6. ORGANIC AND AMMONIA NITROGEN (mg/l as N)
HARDING LAKE. 1975. DEEP STATION I

Depth (m)	Jan 16	Feb 22	Mar 21	Apr 11	May 2	May 7	May 20	May 28	Jun 3
1				.15				.15	
2	.13±.02	.18±.02	.15±.05	.25±.09	.23	.15±.04	.29	.08	
3		.19±.04	.22±.04		.23±.06			.34	
4	.22±.00		.14±.01	.17±.05	.22±.12	.15±.02	.24±.04	.18	
6	.16±.02		.20±.02	.17±.03	.24±.06		.38	.11	.16±.04
8	.12	.12±.02	.16±.04	.16±.01	.18		.42	.12	
10	.18±.01	.17±.06	.13±.04	.32±.06	.29±.13		.15	.20	
12	.21±.04							.16	
14	.16±.03							.16	
16			.20±.10		.34			.16	
18									
20		.14±.02	.16±.04	.43	.10±.02			.20	
25			.19±.10		.20			.14	
30			.23±.02	.25±.08	.21±.07			.12	
35			.20±.00	.20	.15				
40				.32±.06	.20				

(continued)

TABLE 6 (continued)

Depth (m)	Jun 9	Jun 18	Jun 25	Jul 16	Jul 30	Aug 13	Aug 25	Sep 12	Oct 13
1	.22	.23	.21±.10	.26	.19±.08	.19±.08	.12	.23±.00	.27±.17
2	.24±.00		.28±.11	.10	.22±.01	.15±.04	.19±.06	.14±.01	.14±.01
3	.12±.02		.21±.08	.22	.20±.05	.19±.06	.10	.14±.01	.16±.00
4	.16±.03	.22	.24±.09	.14	.15±.05	.16±.08	.11±.02	.17±.07	.17±.02
6	.26	.18	.15±.05	.29	.22±.01	.13±.04	.14±.06	.26±.11	.18±.07
8	.18	.12	.10±.05	.12	.20	.19±.07	.17±.05	.16±.02	.21
10	.15±.04	.14	.16±.03	.09	.19±.10	.17±.06	.22	.17±.05	.25±.10
12	.18	.10	.18±.01		.20±.04	.18	.18	.10±.05	.17±.11
14	.11	.25		.11	.29±.04	.17±.06	.12±.04	.23±.08	.16±.04
16	.19	.14		.21±.14	.18±.02	.15±.06	.17±.01	.18±.06	.18
18	.09±.03	.15	.27	.10	.20±.02	.27±.03	.30±.02	.19±.07	.28
20	.23±.04			.09	.18±.05	.20±.06	.14±.02	.21±.11	.20±.06
25	.14±.04	.19	.16±.04	.10	.17±.07	.22±.10	.18	.12±.04	.15±.07
30	.11±.06	.06		.27	.20±.04	.11±.03	.12±.00		.20±.02
35		.24		.14	.21			.68	
40									

TABLE 7. ORGANIC AND AMMONIA NITROGEN (mg/l as N) HARDING LAKE. 1975. SHALLOW STATIONS

Depth	February 22				March 21			
(m)	S-I	S-II	S-IV	S-V	S-I	S-II	S-IV	S-V
1		.10					.28±.05	
2							.14	
3							.10	
4		.12						
5								
6		.14±.00						
7								
8		.18						
9								
10		.13±.03						
11								
12		.13±.01						
	April 11				May 3			
1		.25±.06	.21				.20±.03	
2		.16±.03	.21±.04					
3			.14±.01					
4		.19±.08						
5								
6		.13±.03						
7								
8		.14±.02						
9								
10		.17±.02						
11								
12								

(continued)

TABLE 7 (continued)

Depth (m)	May 28 S-I	S-II	S-IV	S-V	June 18 S-I	S-II	S-IV	S-V
1	.30		.13		.14			.15±.06
2	.52		.15				.13	.19±.00
3	.23		.18		.30±.05			.22
4	.03							
	July 16				July 30			
1	.24			.11	.11±.01			.21±.01
2	.20			.16	.21±.05			.09±.02
3	.14				.18±.08			.18±.09
4	.11				.12±.04			
	August 13				August 25			
1	.30±.08	.37		.28±.12				.18±.04
2	.33±.16			.10	.10			.17±.03
3	.25±.12			.13±.00	.22±.02			.12
4	.37±.06							
	October 13							
1	.20±.06			.16±.01				
2	.19±.13			.12±.02				
3	.18±.03			.36±.20				
4	.22±.12							

Phosphorus--

For reasons cited in the Methods section, the most successful phosphorus measurements were of total phosphorus made during part of 1975. Analysis of samples taken after August 13, 1975, was not completed before the end of the project due to potential contamination of the ammonia and organic nitrogen measurements that would be caused by use of the total phosphorus digestion agent, ammonium persulfate, in the laboratory. The total phosphorus data is illustrated in Figure 14.

The seasonal cycle of total phosphorus is undramatic and shows little change except for shifts in the depth of the peak concentration. It would be unexpected that the total phosphorus would exhibit a seasonal change in terms of average concentration in a well oxygenated lake with a minimum number of point and nonpoint nutrient inputs. The features of the seasonal cycle are similar to those reported by Stewart and Markello (1974) which also exhibit a fairly constant average with peak concentrations found at discrete depths.

Total nitrogen and total phosphorus, being collective parameters, clearly indicate the comparative nutrient status of the lake. The concentration of individual species of nutrients, especially dissolved inorganic forms, depend largely on relative rates of biological uptake and release whereas total forms indicate the active pool of nutrients in the water column. These parameters are also more frequently reported in the literature and may be more reliable analytically for the class of oligotrophic lakes where analysis problems are frequent at levels commonly close to the detection limit.

To illustrate the relative status of Harding Lake, Table 8 has been compiled to tabulate some of the nutrient values for oligotrophic lakes.

In general, the total nutrient status of Harding is in the range of other lakes identified as oligotrophic. The upper limits of these ranges appear high in some cases but relatively high peaks commonly occur in the nutrient profiles. It is known that plankton tend to stratify at discrete depths (Baker and Brook, 1971) and sampling such strata would tend to give high total nutrient values. The peak total phosphorus values in Harding lie

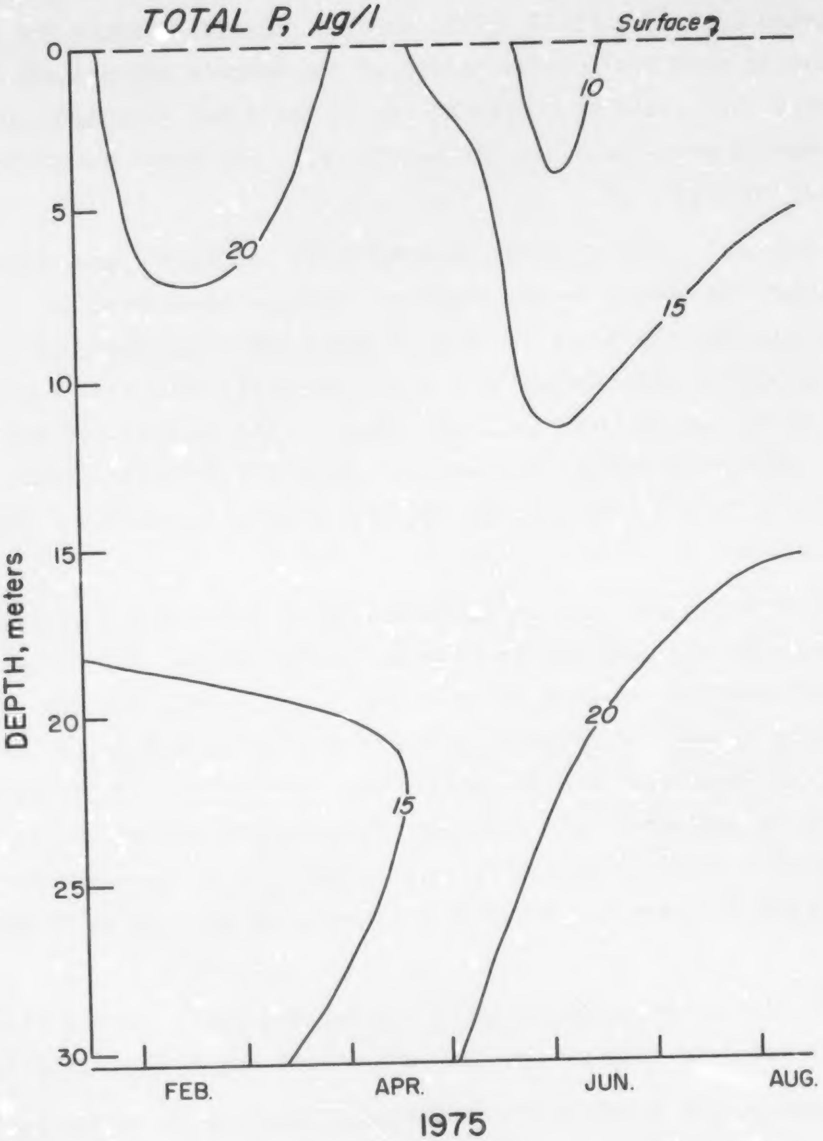


FIGURE 14

TOTAL PHOSPHORUS ISOPLETHS. HARDING LAKE during summer at depths in the range of 15-20 m, the same depth range at which the peak photosynthetic pigment concentrations lie, indicating phytoplankton stratification at those depths.

TABLE 8. NUTRIENT VALUES FOR OLIGOTROPHIC LAKES

Lake	Total P(μg/L)	Total N(μg/L)	Source
Mowich	2-4	15-135	Larson, 1973
Nordford	5	0-180	Strøm, 1932
Vorderer Finstertaler See	1-14	40-270	Pechlaner, 1966
Tahoe	2-20	100-150	Lake Tahoe Area Council, 1971
Superior	8-15		Gruending & Malanchuk, 1974
Char	8		Schindler, *et al.*, 1974
Harding	6-20	70-300	

BIOLOGICAL LIMNOLOGY

Algae

Autotrophic Primary Production--

Actual counts of the plankton, with emphasis on the algae present in the water column, were only conducted once, for samples of September 28, 1974, at Deep Station I. The results of these counts are presented in Table 9 and Figure 15. Other observations were occasionally made concerning the algal composition and Table 10 contains a list of all algae identified to April 1975.

During the three years of this project, algal growth dynamics were studied in two major ways. Chlorophyll *a* measurements, which have often been used to estimate biomass and to evaluate growth were taken; and, algal primary production was assessed using a method of measuring the uptake of radioactive ^{14}C-labeled bicarbonate (Steemann-Nielsen, 1952).

TABLE 9. PLANKTON COUNTS (CELLS/LITER) HARDING LAKE. SEPTEMBER 28, 1974. DEEP STATION I

Species	Depth in meters of sample								
	2	4	6	8	10	16	20	24	30
Bacillariophyceae									
Asterionella formosa	8×10^2	2×10^3	3×10^3	2×10^3	4×10^2	9×10^3	5×10^3	2×10^3	1×10^4
Cocconeis sp.					4×10^2				
Cyclotella sp.	3×10^3	8×10^2	2×10^3		4×10^3	2×10^3	2×10^3	3×10^3	5×10^3
Cymbella sp.	8×10^2								8×10^2
Diatoma elongatum							8×10^2		
Melosira italica						9×10^3	8×10^3	1.5×10^4	1.8×10^4
Nitzschia sp.						8×10^2	2×10^3		
Synedra nana		8×10^2						3×10^3	2×10^3
Chlorophyceae									
Ankistrodesmus setigerus	2×10^2	5×10^3	2×10^3	6×10^3	2×10^3				
Cosmarium subtumidium								8×10^2	
Crucigenia tetrapedia		8×10^2							
Staurastrum curvatum			8×10^2						
Chrysophyceae									
Diceras phaesolus	2×10^3	8×10^2	3×10^3	2×10^3	2×10^3				
Dinobryon borgei		8×10^2		2×10^3					
D. crennulatum	2×10^3	6×10^3	6×10^3	6×10^3	4×10^3				

(continued)

TABLE 9 (continued)

Species	Depth in meters of sample 2	4	6	8	10	16	20	24	30
D. crennulatum, loricas	4.0×10^{4}	5.4×10^{4}	3.4×10^{4}	5.0×10^{4}	2.8×10^{4}	4×10^{3}		8×10^{2}	
D. sociale					4×10^{2}	2×10^{2}			
D. sociale, loricas			8×10^{2}		3×10^{3}	3×10^{3}		8×10^{2}	2×10^{3}
Dinobryon sp. unidentified			8×10^{2}						
Dinobryon sp. unidentified, loricas							4×10^{3}		
Mallomonas globosa	4×10^{3}		8×10^{2}	2×10^{3}	4×10^{3}				
Ciliates									
unidentified	4×10^{3}	5×10^{3}		8×10^{2}	3×10^{3}	2×10^{3}	6×10^{3}	7×10^{3}	2×10^{3}
Cladocera									
Daphnia sp.		8×10^{2}							
Cryptophyceae									
Cryptomonas sp.	2×10^{3}	2×10^{3}	2×10^{3}	8×10^{2}	8×10^{2}	8×10^{2}	8×10^{2}	2×10^{3}	
C. marssonii					2×10^{3}				
Rhodomonas minuta	3.3×10^{4}	4.6×10^{4}	6.2×10^{4}	4.1×10^{4}	1.9×10^{4}	3.0×10^{4}	3.1×10^{4}	3.6×10^{4}	2.0×10^{4}
Cyanophyceae									
Oscillatoria borneti							2×10^{3}	3×10^{3}	1.1×10^{4}
Dinophyceae									
unidentified					4×10^{2}				

(continued)

TABLE 9 (continued)

Species	Depth in meters of sample								
	2	4	6	8	10	12	20	24	30
Flagellates									
unidentified	$2.3x10^4$	$9\ x10^3$	$2.2x10^4$	$1.4x10^4$	$1.6x10^4$	$3.8x10^4$	$1.7x10^4$	$2.7x10^4$	$1.8x10^4$
Protozoa									
Didinium sp.			$2\ x10^3$	$4\ x10^3$	$2\ x10^3$	$7\ x10^3$	$5\ x10^3$	$5\ x10^3$	$8\ x10^2$
unidentified			$2\ x10^3$						
Rotatoria									
Kellicottia longispina lorica					$4\ x10^2$				
Keratella sp.					$4\ x10^2$	$8\ x10^2$			
Polyartha major								$8\ x10^2$	$8\ x10^2$

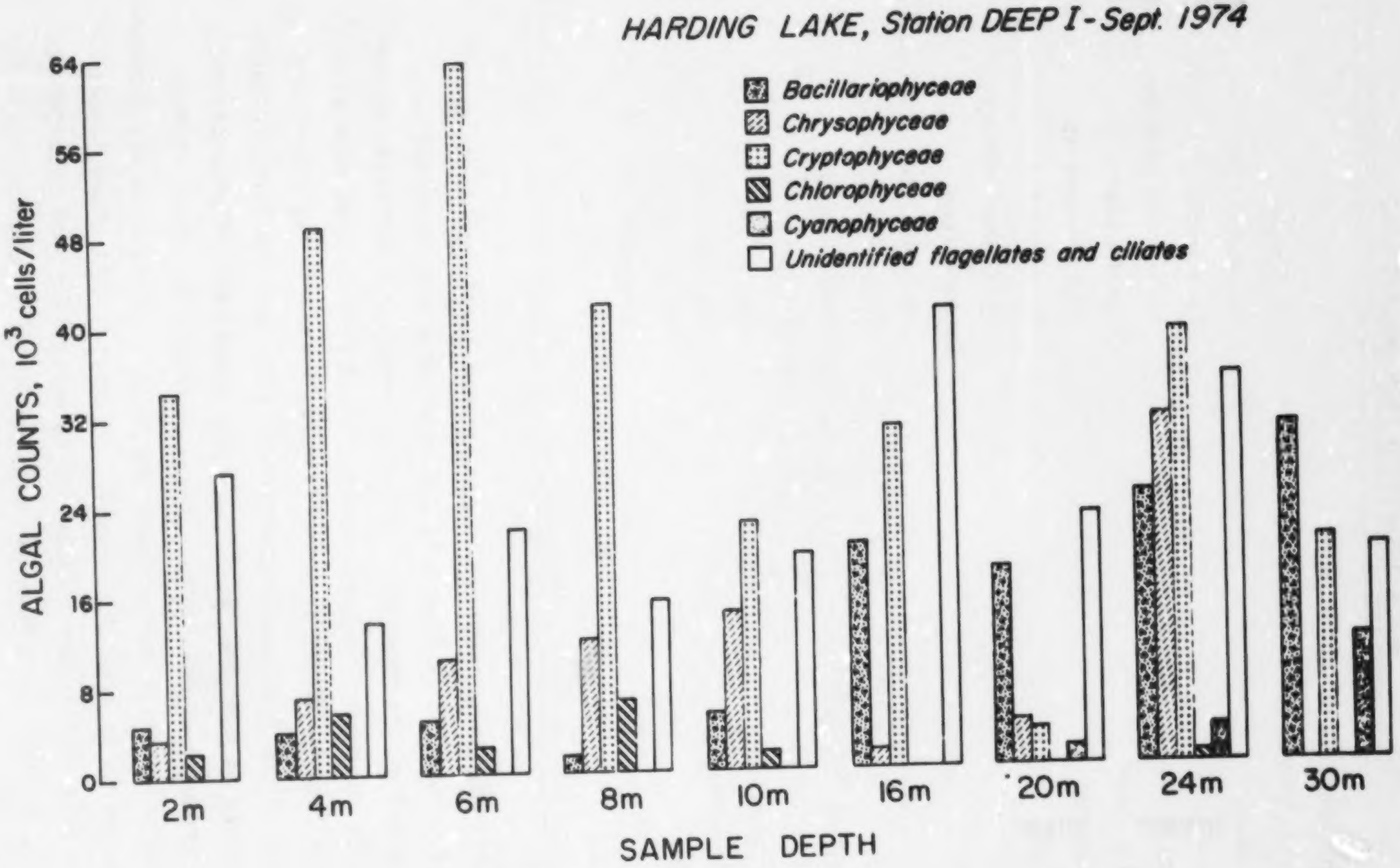


FIGURE 15

ALGAL COUNT. SEPTEMBER 28, 1974. HARDING LAKE

TABLE 10. ALGAE IDENTIFIED FROM HARDING LAKE

Bacillariophyceae
- *Asterionella formosa*
- *Cocconeis* sp.
- *Cyclotella* sp.
- *Cymbella* sp.
- *Diatoma elongatum*
- *Melosira italica*
- *Nitzschia* sp.
- *Synedra nana*

Charophyceae
- *Chara* sp.

Chlorophyceae
- *Anikistrodesmus setigerus*
- *Cosmarium subtumidium*
- *Crucigenia tetrapedia*
- *Staurastrum curvatum*

Chrysophyceae
- *Diceras phaseolus*
- *Dinobryan* sp.
- *D. borgei*
- *D. crenulatum*
- *D. sociale*
- *Mallomonas globosa*

Cryptophyceae
- *Cryptomonoas* sp.
- *C. marssonii*
- *Rhodomonas minuta*

Cyanophyceae
- *Anabaena* sp.
- *Coccochloris* sp.
- *Desmonema* sp.
- *Gloeotrichia* sp.
- *Nostoc* sp.
- *Scytonema* sp.
- *Oscillatoria borneti*

Dinophyceae
- *Ceratium* sp.

The results of the chlorophyll *a* measurements during the last year of the project are presented in Figure 16 and other data are contained in Tables A-2 and A-3 of the Appendix. Early in the project difficulties were encountered with chlorophyll *a* measurement. These difficulties were eliminated by increasing the amount of water filtered to nearly two liters and utilizing a low-volume 4-cm spectrophotometric cell, and the first reliable data were obtained on August 6, 1973. Routine measurement of phaeopigments, the breakdown products of chlorophyll, began on August 10, 1974. Before that date, some chlorophyll measurements are falsely high due to the measurement of phaeopigments as true chlorophyll. It appears that phaeopigments found here are only significant relative to chlorophyll *a* when snow-covered ice is present and light is reduced to very low levels throughout the water

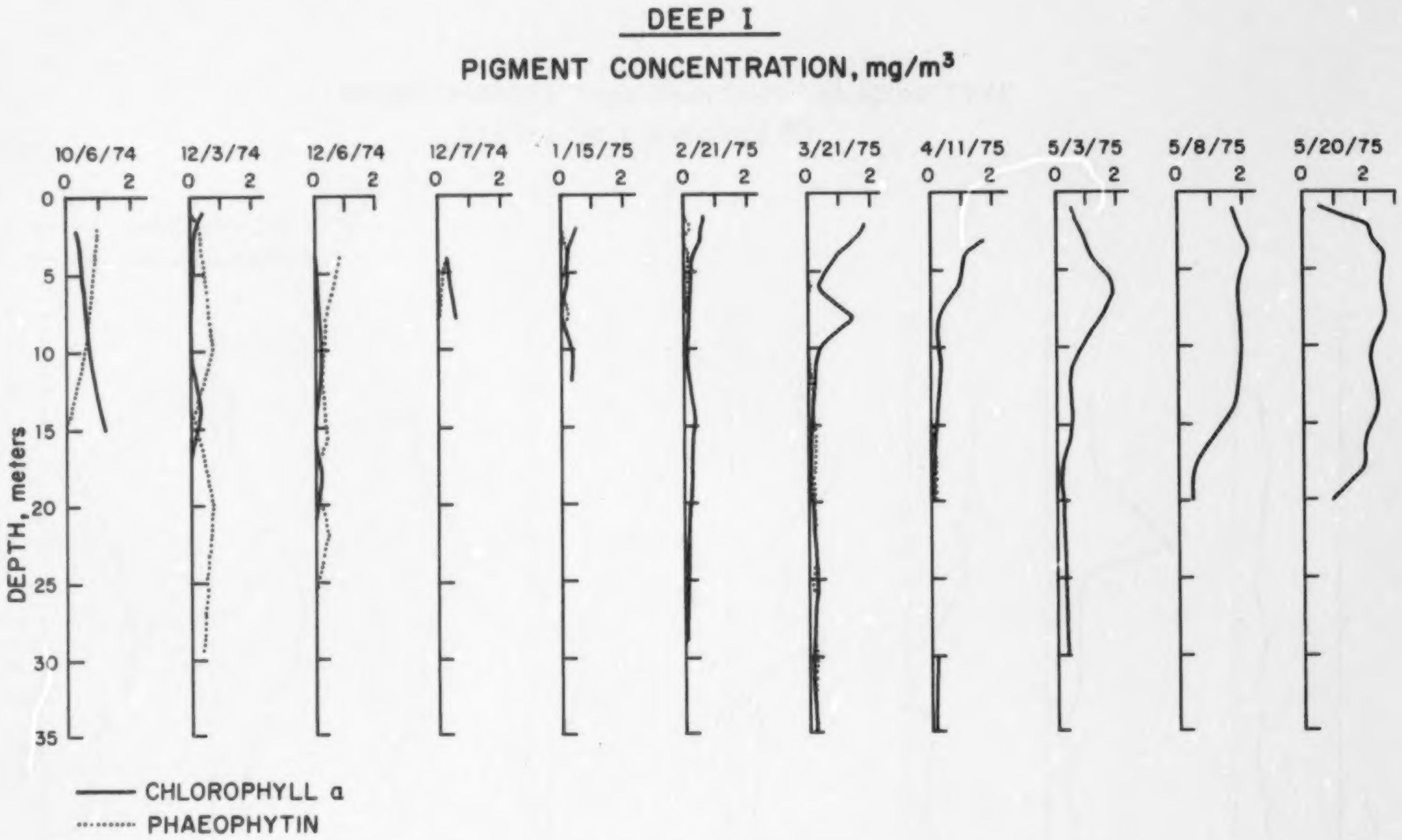


FIGURE 16

ALGAL PIGMENT CONCENTRATION, HARDING LAKE

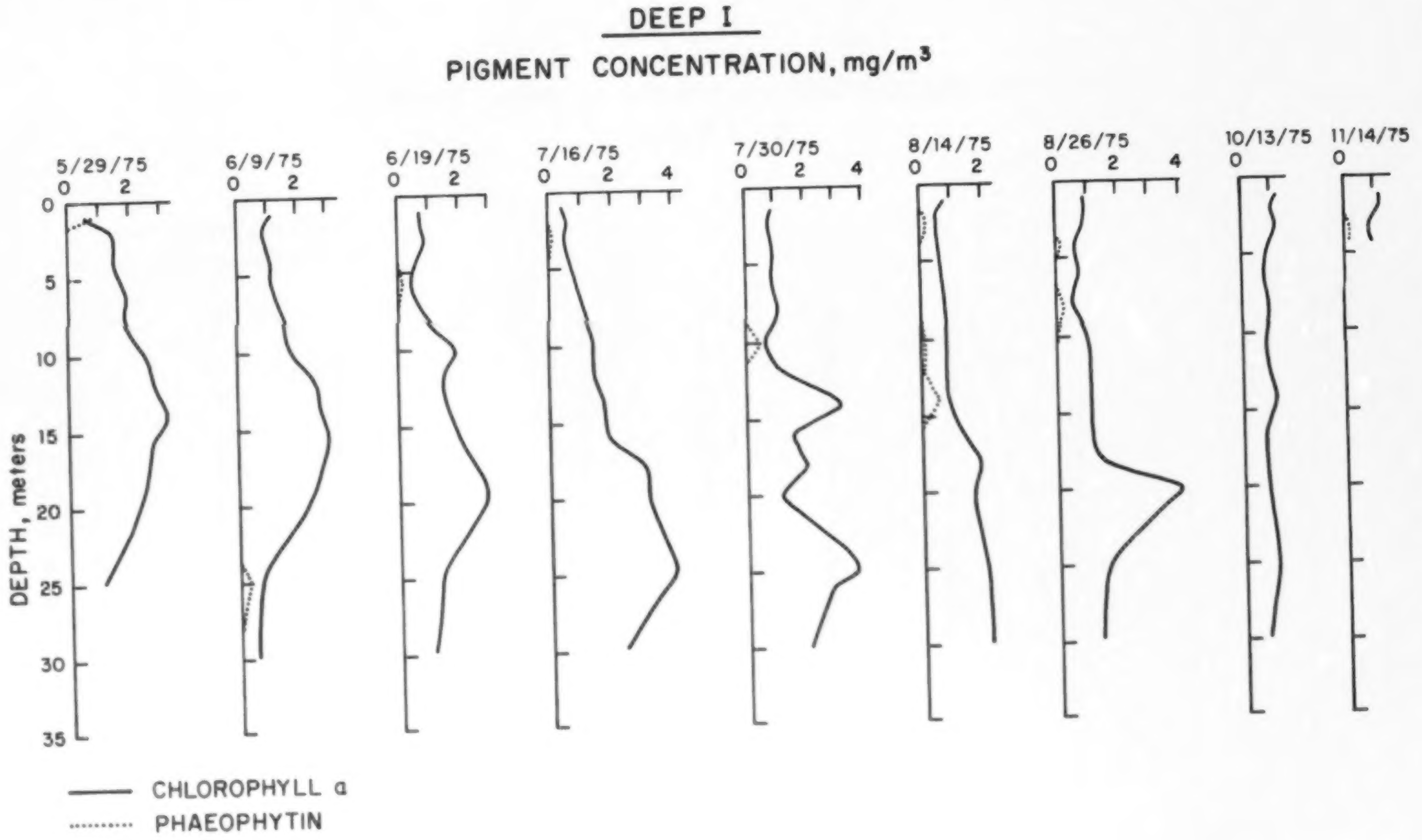


FIGURE 16 (CONTINUED)
ALGAL PIGMENT CONCENTRATION, HARDING LAKE

column. Unfortunately, the large size of the finned sea cell of the submarine photometer available to this project did not allow measurement of light extinction under the ice seal so we were unable to quantify this inverse relationship between light and phaeopigment concentration.

Figures 17 and 18 present the results of the light and dark bottle experiments utilizing NaH^*CO_3 to measure carbon fixation by the algae. The experiment was routinely run only to 30 m, considerably below the 1% light level during strong summer sunlight (See Figure 10), but this is seen to be somewhat inadequate for certain dates when measurable fixation was still occurring at 30 m.

Table 11 presents the results of integration over depth of the chlorophyll *a*, carbon fixation measurements, and light radiation received at the surface. The data of January 15, February 21, and November 14, 1975, are questionable because the Sign Rank test showed no significant difference between the mean distribution of the light and dark bottles for these dates. March 21, 1976, data are also not considered accurate as the light and dark bottles were incubated in an incorrect sequence relative to the depths at which the water was taken.

No relationship was found between these measurements. Attempts were also made to relate chlorophyll *a* concentration and fixed carbon (mg/m^3) at each depth, on each day when both were measured, and no pattern was found.

Figure 19 presents a means of estimating the annual primary production assignable to the planktonic algae. This figure shows that estimates from our data for 1974 and 1975 are significantly different, at least between June 20 and September 28. This difference most probably occurs because of difficulties with the quality of the purchased radioactive tracer. All experiments up to that of June 19, 1975, (and additionally, those of October 14 and November 14, 1975) were run with a batch of tracer of good quality and the calibration value is acceptable, $6.68 \times 10^6 \pm 4.71 \times 10^4$ cpm/ml. All other experiments were run using a different batch of higher variability $3.73 \times 10^6 \pm 1.40 \times 10^5$ cpm/ml. The above calibrations are specific to our standards and counting situation, but the fact that this batch is highly variable has been verified by others using this batch

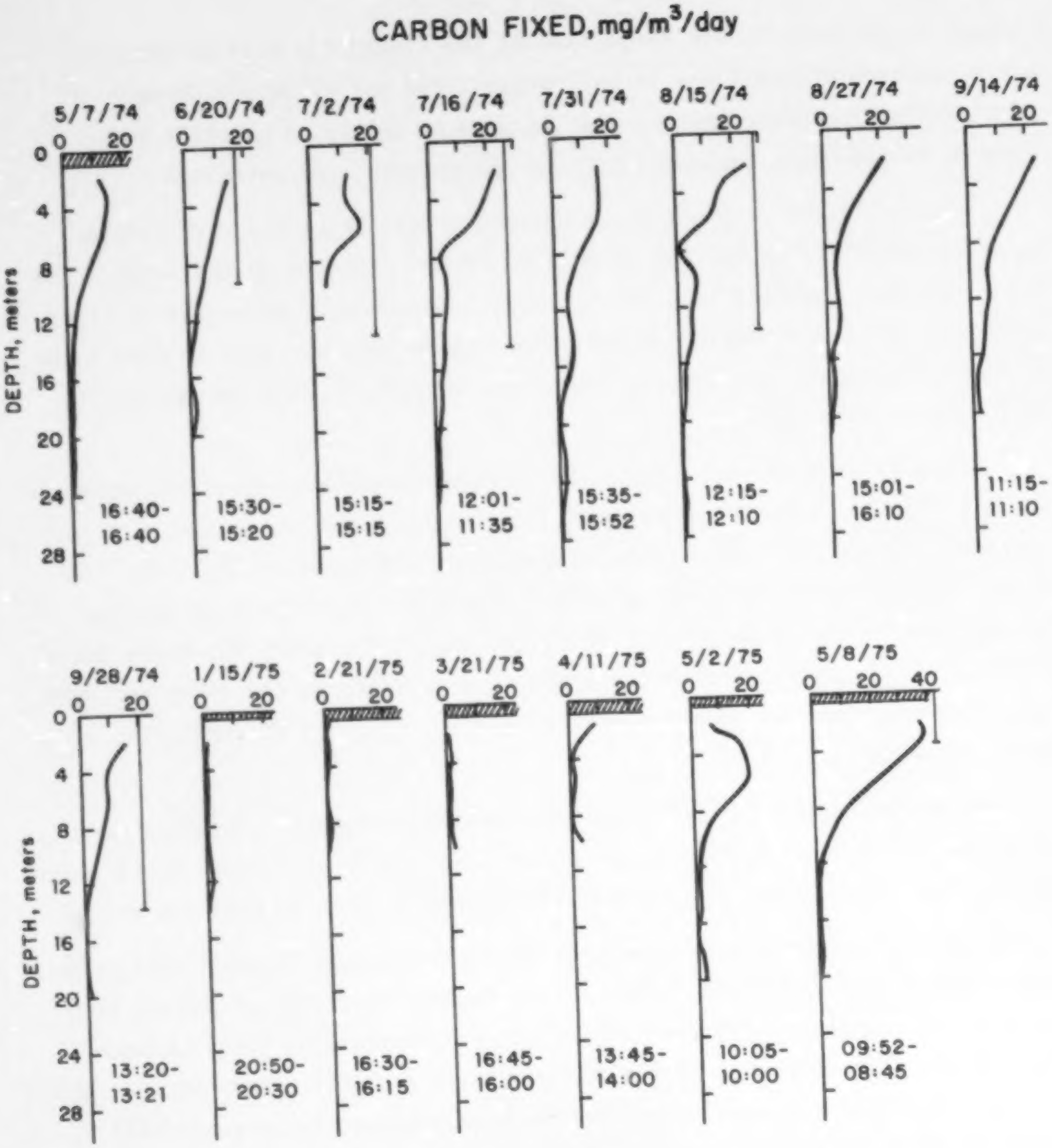


FIGURE 17

ALGAL PRIMARY PRODUCTION. STATION DEEP I, HARDING LAKE, ALASKA. ICE THICKNESS AND SECCHI DEPTH INDICATED.

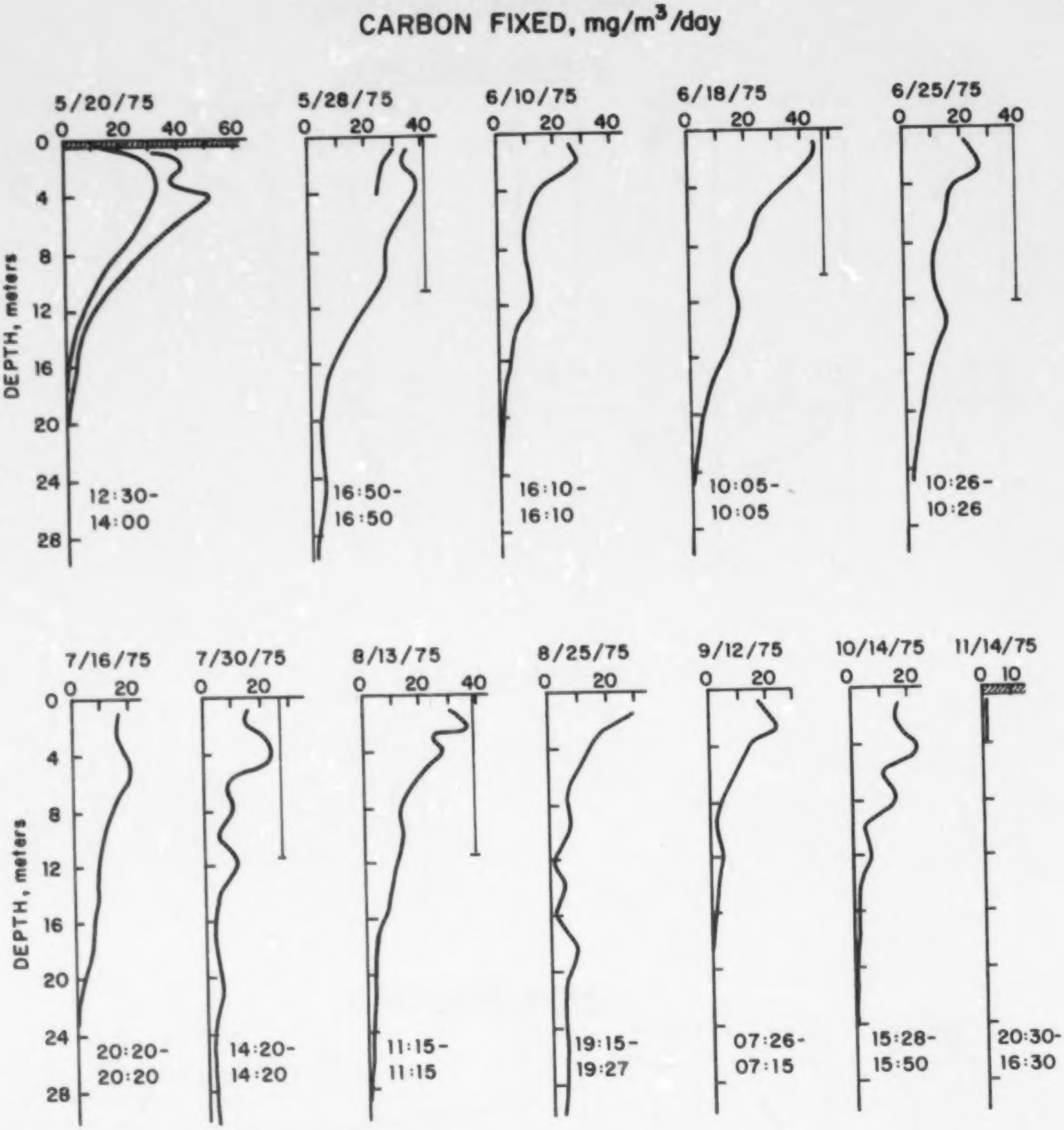


FIGURE 17 (CONTINUED)

ALGAL PRIMARY PRODUCTION. STATION DEEP I, HARDING LAKE, ALASKA. ICE THICKNESS AND SECCHI DEPTH INDICATED. INNER LINES FOR MAY 20 AND 28, 1975 INDICATE VALUES CORRECTED FOR LAKE MORPHOMETRY.

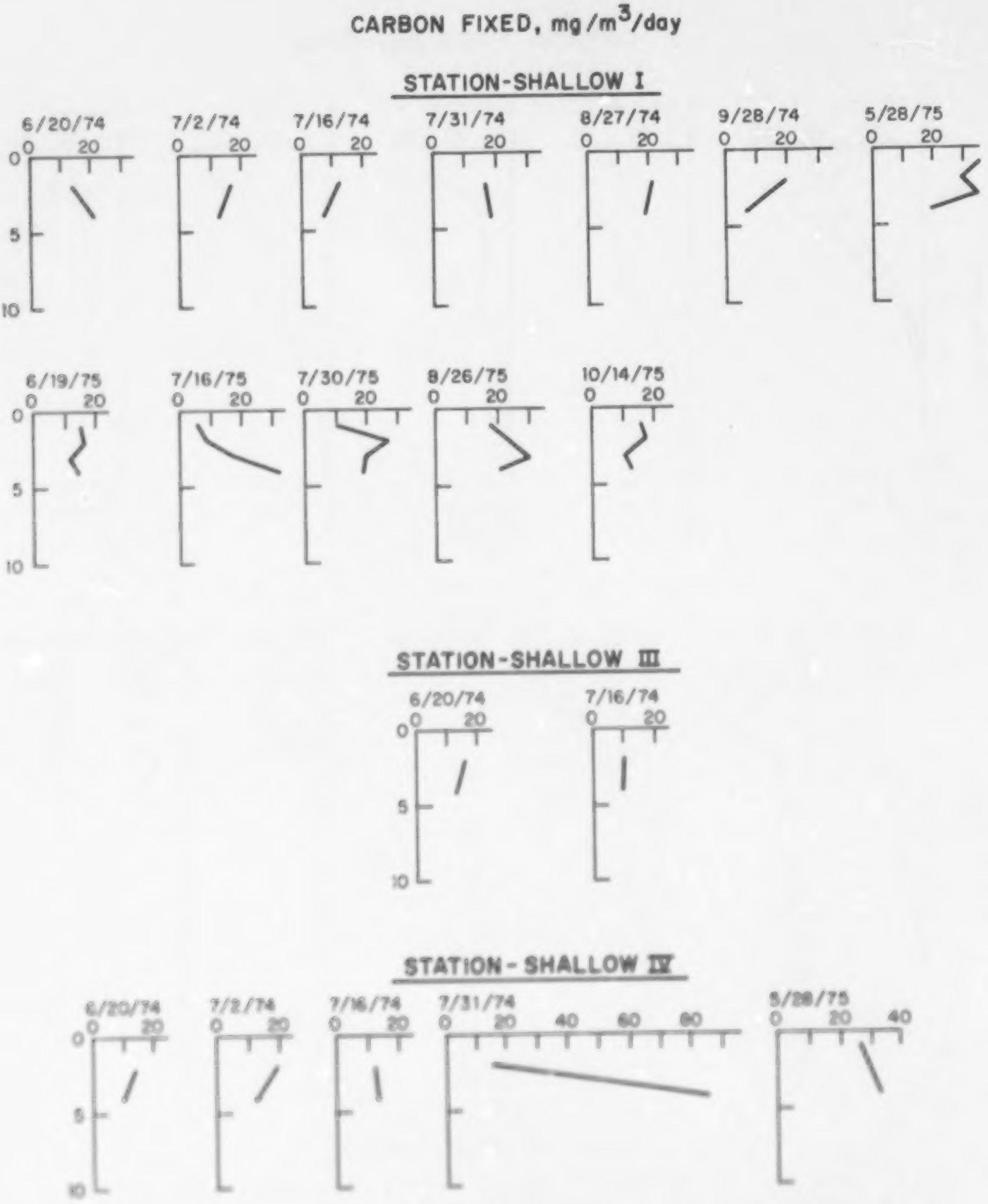


FIGURE 18
ALGAL PRIMARY PRODUCTION, HARDING LAKE

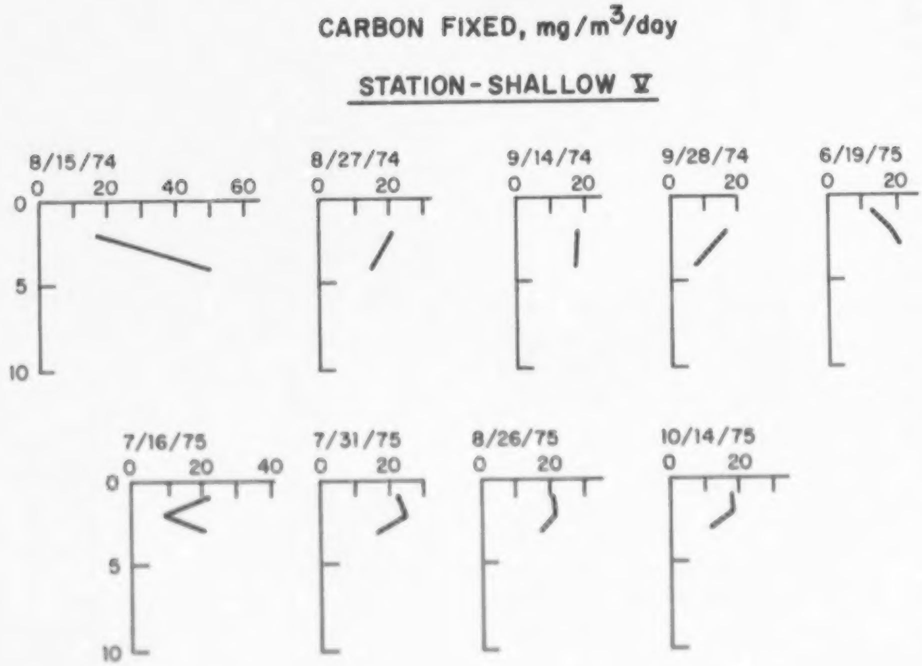


FIGURE 18 (CONTINUED)

ALGAL PRIMARY PRODUCTION, HARDING LAKE

TABLE 11. INTEGRAL VALUES OF ALGAL GROWTH PARAMETERS AND INCIDENT RADIATION. HARDING LAKE. DEEP STATION I

Date	Chlorophyll *a* (mg/m^2)			C-14 production ($mg/m^2/day$)	radiation ($gm\text{-}cal/cm^2/day$)
8/06/73	8.7		(to 10m)		
8/27/73	7.8		(to 10m)		
10/18/73	3.9		(to 4m)		
12/04/73	15.0		(to 30m)		
3/14/74	14.3		(to 35m)		
4/06/74	20.7		(to 35m)		
5/07/74				118.8	
6/20/74				98.0	
7/02/74				94.4	
7/16/74				156.8	618.6
7/31/74				154.8	
8/15/74				138.0	
8/27/74				124.4	
9/14/74				141.6	273.0
9/28/74*				88.8	316.5
10/06/74	8.5		(to 15m)		
12/03/74	2.4		(to 30m)		
1/05/75	2.4		(to 12m)	1.0	
2/21/75	6.5		(to 30m)	10.0	
3/21/75	13.4			7.6	
4/11/75	12.9			11.3	385.9
5/02/75	21.4	(5/5/75)		118.9	473.6
5/08/75	31.6		(to 20m)	188.7	377.1
5/20/75	44.6		(to 20m)	401.9	564.8
5/28/75	45.4	(5/29/75)	(to 25m)	447.2	
6/10/75	50.0	(6/09/75)	(to 30m)	194.3	301.7
6/18/75	47.6		(to 30m)	398.1	408.7
6/25/75				297.2	
7/16/75	63.6		(to 30m)	232.0	566.6
7/30/75	53.6		(to 30m)	215.2	371.9
8/13/75	41.9	(8/14/75)	(to 30m)	309.6	419.2
8/25/75	44.0	(8/26/75)	(to 30m)	325.1	203.5
9/12/75				128.3	
10/14/75	30.3		(to 30m)	203.8	
11/14/75	3.1		(to 4m)	1.8	

*All chlorophyll *a* measurements prior to this date were calculated by the Strickland and Parsons formula, after this date by the IBP formula.

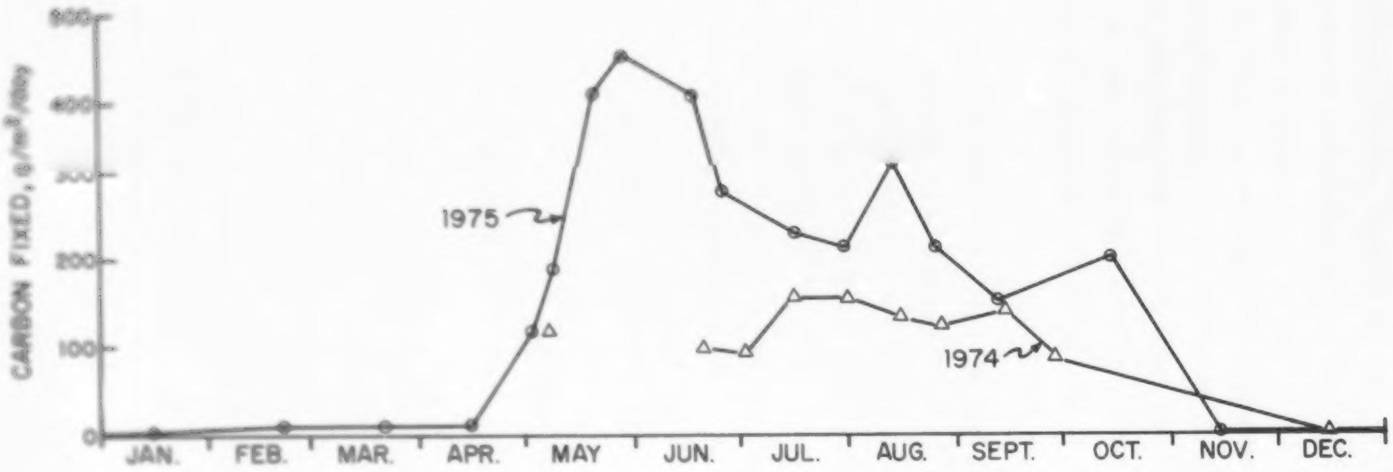


FIGURE 19

ANNUAL ALGAL PRIMARY PRODUCTION. HARDING LAKE

(Williams, S., 1976 personal communication; Alexander, V., 1976, personal communication). This latter batch contained two populations of unknown size of different specific activities one of which is approximately double the other. Because ampules for standard preparation were not drawn at random from the entire batch, there is no way to assign ampules used to anything more accurate than a value somewhere between the two specific activities according to the particular ampules drawn for standard preparation by each user. This problem was not found before much work had been accomplished by all groups and individuals using this batch of tracer due to the stockpiling of sample filters, which was necessitated by the remote location of field sites.

Figure 19 indicates that the activity estimated by our standards for the second batch is probably too low, allowing overestimation of productivity and production. Note the closeness in daily fixation on May 7, 1974, and two dates in early May, 1975, when the same, more reliable first batch of tracer was being used. In any case, our estimate of annual production, at 47.8 gm C/m^2/year is most undoubtedly high due also to the fact that the daily productivity was not corrected for lake morphometry. Some estimate of the effect of these corrections can be made by reference to Figure 17 where productivity at all depth at Deep Station I for May 20, 1975, is plotted both corrected and uncorrected for the amount of lake surface area underlain by water of the depth of the measurement.

On the whole, there was no significant added variance component between shallow stations as compared to within the stations when Bartlet's test for homogeneity of variance and a Model II one-way analysis of variance was performed on the shallow-station data. Thus it is valid to compare any one shallow station to the comparable section of the Deep Station I. In a comparison of this type, the first 4 m of the data for May 28, 1975, at Deep Station I is plotted both corrected and uncorrected for lake morphometry in Figure 17, and the corrected inner line can be compared to that representing production measured at Shallow Stations I or IV (Figure 18) on that date. The areal production obtained by integration of the inner corrected line is not significantly different from that of either of the shallow stations. Nor is it significantly different from that of the uncorrected line for the first

4 m of Deep Station I. Thus, with few exceptions, littoral area production is adequately represented by the measurements in the upper 4 m of Deep Station I. It can be noticed from Figures 17 and 18 that the shallow stations were often run a day later or earlier than the deep station, and variations due to weather changes show effect. These variations however, are not large enough to warrant further consideration in estimating annual algal production. The two high values near the bottom of Shallow Station IV on July 31, 1974, and at Shallow Station V on August 15, 1974, may be artifacts due to coprecipitation of the bicarbonate with oxidizing iron, since deposits of red iron precipitates have been noted in the littoral of this lake, or it may be a true effect of optimum light as these are both gravel-bottomed stations, or the effect may be of optimum local nutrient availability.

Comparison of the algal primary productivity and production of Harding Lake to other well-studied lakes is informative (Table 12). Unfortunately, the best-studied high-latitude lakes are found in the arctic and may not be strictly comparable to subarctic Harding Lake.

TABLE 12. ANNUAL ALGAL PRIMARY PRODUCTION. HIGH-LATITUDE LAKES

Lake and Latitude	Annual	gm C/m^2	
Char Lake 72°42'N	1969	5.8	
	1970	6.3	(Kalff and Holmgren,
	1971	7.2	1971)
Meretta 72°42'N	1969	31.2	
	1970	16.5	(Kalff and Holmgren,
	1971	31.7	1971)
Schrader 69°22'N	1959	7.5	
	1961	6.5	(Hobbie, 1964)
Peters 69°19'N	1969	0.9	(Hobbie, 1964)
Harding 64°25'N	1975	47.8	

It should be noted that Peters and Schrader Lakes are both somewhat turbid due to glacial water sources, and that Char Lake is ice covered except for a very short period in late summer, at times remaining ice covered throughout some years. Therefore, the growth of the planktonic algae of these lakes would be expected to be somewhat light limited. Merretta Lake receives sewage from the village of Resolute and is thought to be more productive than nearby Char Lake because of the increased nutrient loading.

Considering Rodhe's (1965) index which considers the shape of the daily productivity curve as well as its integral as summer averages, Harding Lake can be compared to other clear, deep, oligotrophic lakes (Table 13). Rodhe's index is the quotient of a_{max} (maximum production in mg C/m^3/day) divided by Σa (mg C/m^2/day).

TABLE 13. RODHE'S INDEX. SELECTED OLIGOTROPHIC LAKES

Lake	$\frac{a_{max}}{\Sigma a}$	Reference
Byglandsfjorden ∿59°N	0.14	Lande (1973)
Char 72°42'N	0.12	Kalff and Welch (1974)
Tahoe 39°09'N	0.002	Goldman (1974)
Harding 64°25'N	0.11	

The peculiarities of the algal productivity of Lake Tahoe illustrated here are due to the extreme depths at which algal growth occurs as compared to the low maximum production at each particular depth. From the above figures it can be seen that algal primary productivity values would help to classify Harding Lake as oligotrophic. Reports of visable algal blooms on this lake have been attributed by our field crew to probably stem from high amounts of floating tree pollen occurring each spring.

The light regime peculiar to the latitude at which this lake is located presents a different setting than that of temperate lakes (Johnson and Hartman, 1969). This latitude enjoys more sunlight and twilight as a percent of the time in a year: about 62% as compared to 56% for 50°N latitude in the middle of the conterminous states. Proportionally more of the total year's sunlight is experienced here in summer and less in winter. Indeed, from late May to late July, continuous sunlight and twilight occur and no darkness is experienced. Thus the question arises as to whether this extended summer sunlight and reduced winter sunlight influences algal primary production.

The need to conduct carbon-14 algal primary production experiments for 24 hours, because of the low productivity expected in northern waters, is documented (Hobbie, 1964). It has been noted by marine researchers that 24-hour incubations tend to underestimate productivity in comparison to shorter experiments that are summed. This has been attributed to respiration losses of previously fixed labeled carbon during the night period of darkness (Eppley and Sharp, 1975). Due to our particular work regime, coupled with our need to travel 89.6 km (56 miles) to reach the lake, the great majority of our experiments, Figures 17 and 18, were begun late in the day and thus the dark respiration in the light bottles did not involve previously labeled fixed material, but instead, the experiments were usually terminated following the height of the light period.

Diurnal experiments were conducted on June 25-26, 1975, and again on September 12-13, 1975, to assess the 24-hour incubation period by comparing it to the sum of four 6-hour periods. On June 25-26, close to the summer solstice, the lake basin enjoys approximately 21.5 hours of sunlight and 2.5 hours of civil twilight, and no period of darkness. In late September, near the autumnal equinox, the daylight lasts 12.5 hours and twilight lengthens the light period to a total of slightly more than 14 hours.

The results of these experiments are shown in Figures 20 and 21 and Table 14. While this type of experiment would have to be repeated many times to yield results that could be statistically analyzed, and error separated, many interesting results are noted. In June while the pyrheliometer measured early-morning incident radiation almost half that of the evening, fixation was almost immeasurable for the early morning period, A, while that of the evening, D, was sizable. The midday depression of photosynthesis noted in comparing periods A and B of approximately equal light intensity is commonly found in experiments of this type (Wetzel, 1975). It can also be noted that in September the sum of the four 6-hour incubations gives approximately the

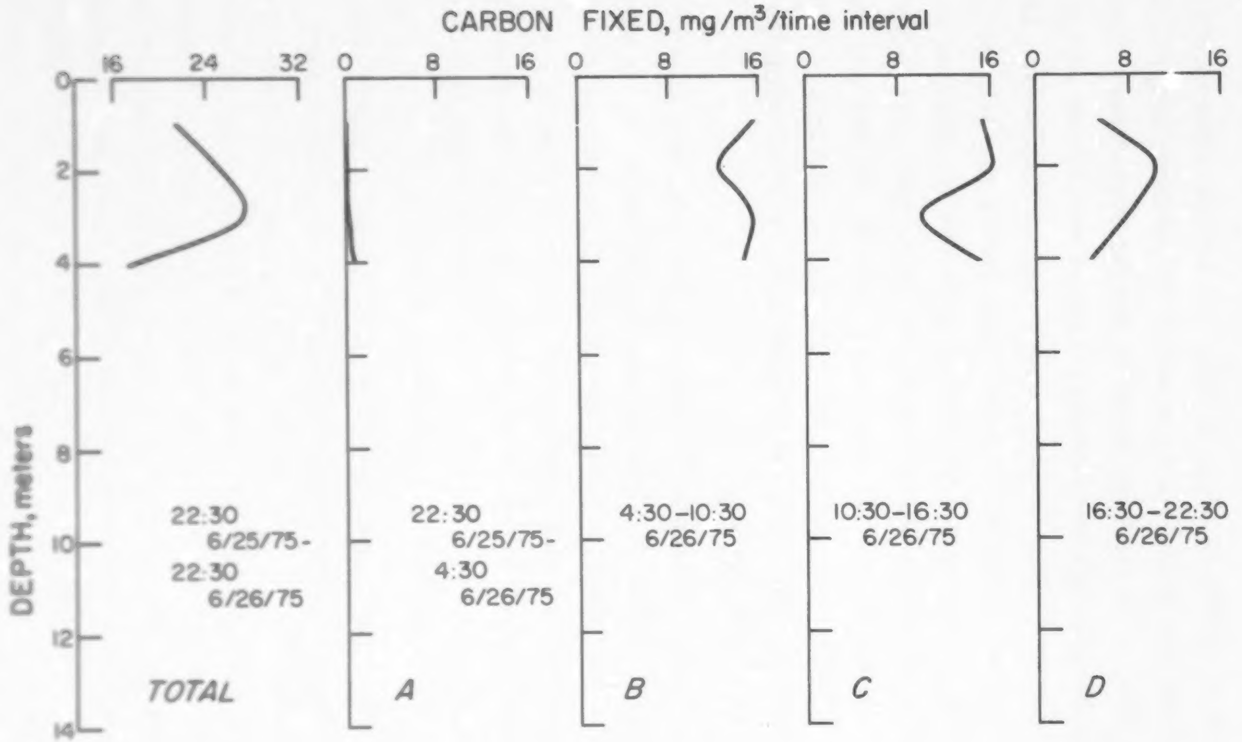


FIGURE 20

DIURNAL PRIMARY PRODUCTIVITY. HARDING LAKE. DEEP STATION I. JUNE 25-26,'75

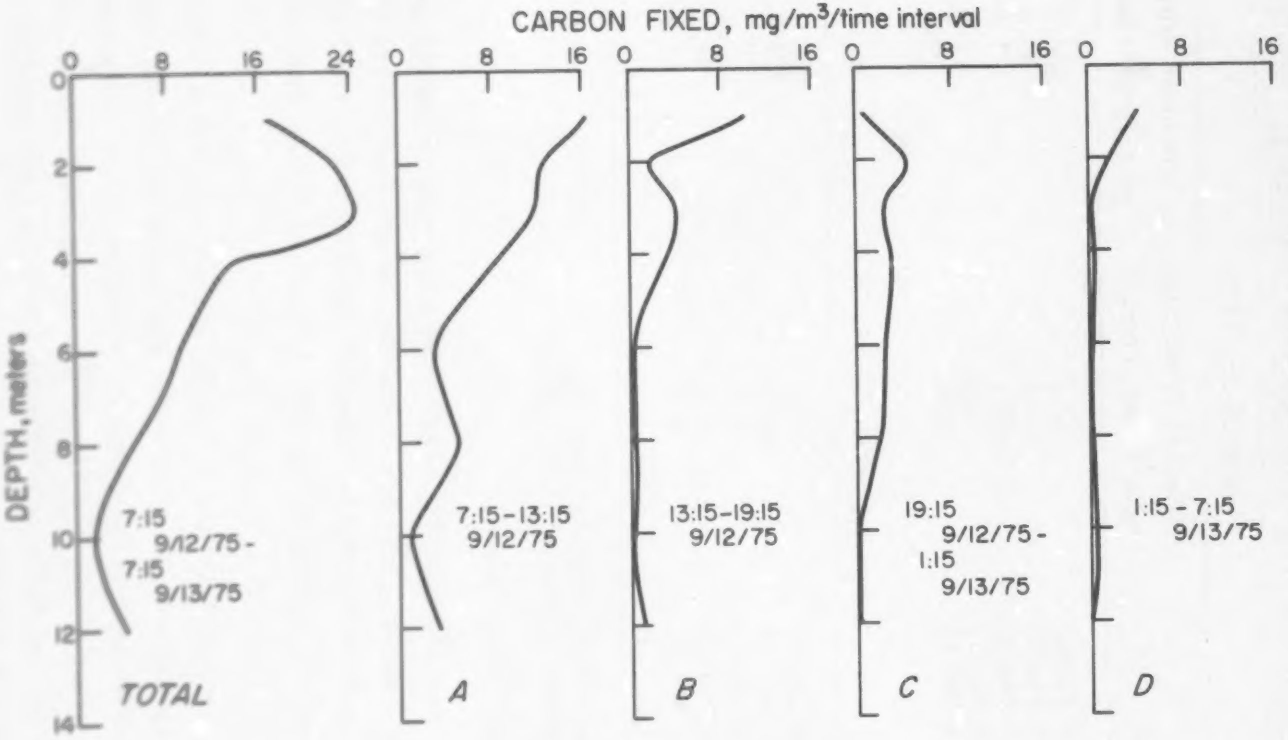


FIGURE 21

DIURNAL PRIMARY PRODUCTIVITY. HARDING LAKE. DEEP STATION I. SEPT. 12-13, 1975 same fixation as the 24-hour incubation, while in June the 24-hour fixation seems to be an underestimate.

TABLE 14. TIME-OF-DAY EFFECTS ON CARBON-14 EXPERIMENTS. HARDING LAKE.

Time Period*	Integral Production mg/m^2/time interval	Incident Radiation $gm\text{-}cal/cm^2$/time interval
June 25-26, 1975		
22:30 - 22:30 (24 hours)	72.8	580.5
22:30 - 4:30 (6 hours)	0.7	43.8
4:30 - 10:30 (6 hours)	43.4	171.9
10:30 - 16:30 (6 hours)	42.6	266.6
16:30 - 22:30 (6 hours)	23.8	98.2
September 12-13, 1975		
7:15 - 7:15 (24 hours)	113.6	283.4
7:15 - 13:15 (6 hours)	66.0	98.2
13:15 - 19:15 (6 hours)	18.5	86.0
19:15 - 1:15 (6 hours)	19.6	54.5**
1:15 - 7:16 (6 hours)	6.8	43.9**

* All times noted are Alaska Standard Time
** Moisture condensed on dome of pyrheliometer

Heterotrophic Algal Production--

Measurements of heterotrophic algal production were attempted twice during this study. Rodhe (1955) has speculated on the possibility of higher relative importance of heterotrophic compared to autotrophic algal production during winter in lentic aquatic ecosystems at high latitudes when sunlight is very reduced.

The first attempt of February 21, 1975, was not successful. Radioactive carbon labeled galactose was the only substrate tested on natural populations sampled at 20 m and incubated for 6 hours. Fixation of the radiocarbon was so slight as to be insignficantly higher than background. The second experiment followed the work of Maeda and Ichimura (1973) and the substrates presented were glucose and acetate. It is assumed, in this type of experiment, that heterotrophic bacteria are the main glucose-fixing organisms, while acetate fixation can also be carried out by small flaggelated green algae as a dark reaction. To separate out the algal fixation, streptomycin, at 3 mg/l, is added to kill the bacteria that might also find the acetate an acceptable substrate.

While this technique can be questioned because of several inherent weaknesses, some information was gained. Regarding Figure 22, it is seen that streptomycin was only slightly more effective in depressing the fixation of glucose (to 73% at the highest concentration) than the fixation of acetate (to 87%). This could be attributed to a weakness of the technique as explained by the fact that the activity of streptomycin is somewhat specific to gram-negative rod-shaped bacteria. The use of a broad-spectrum antibiotic that does not affect algal cells or an algastat that does not affect bacteria would improve the technique. In this particular experiment glucose fixation was not significantly reduced by the added bactericide most probably because the amount of glucose added was inadvertently large enough to promote algal fixation. The work of Wright and Hobbie (1965) has shown that heterotrophic primary production likely is carried out under two separate mechanisms. With low concentrations of simple organic substrates, bacteria are able to utilize them for growth by an active transport process explainable by Michaelis - Menten kinetics equations. When higher concentrations of substrates are available, the algae probably become able to utilize them through a passive transport process, wherein the substrate diffuses through the cell wall when the surrounding concentration becomes higher than the internal concentration.

Thus, our experimentation, while not being intensive enough to allow calculation of uptake velocities or upper limits of in-lake concentrations of simple organic substances, has shown that heterotrophic primary production by algae as well as bacteria may be an important wintertime activity in Harding Lake.

Management Implications of the Algal Studies--

The relationship between lakeside development and degradation of lake water quality has been recognized for some time and the phenomenon has been termed "cultural eutrophication." This recognition has generated public

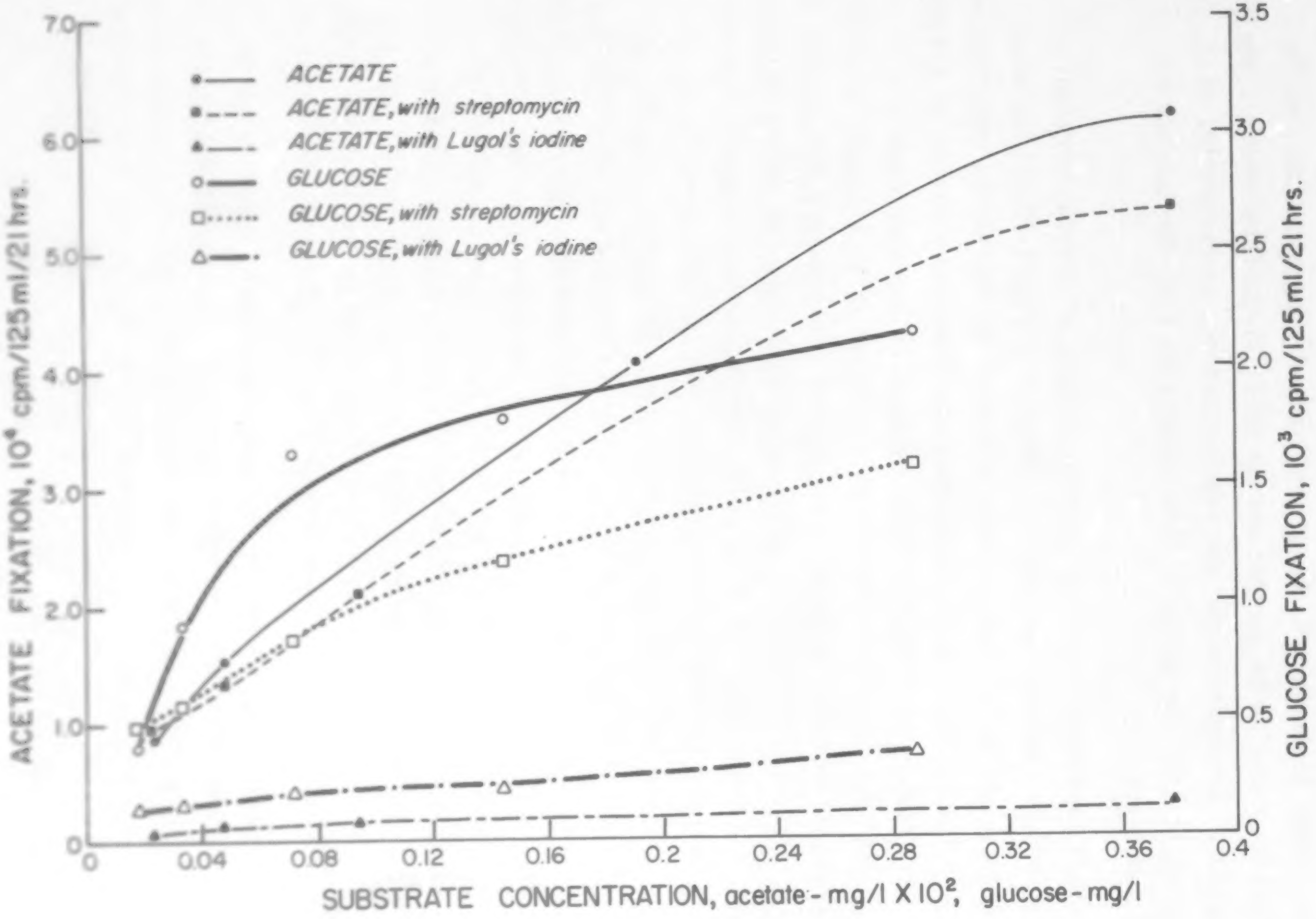


FIGURE 22
HETEROTROPHIC PRODUCTION. HARDING LAKE. NOV. 14, '75

concern that lakes be protected from development that would prove to have a detrimental effect on water quality. Predicting the allowable level of development for a particular lake, however, has proved difficult.

The most visible evidence of water quality degradation consists of nuisance growths of algae with a resulting decrease in water clarity. Limnologists have recently developed empirical models based on the relationship between the phosphorus input and the resultant algal growth (Vollenweider, 1969b, 1971; Bachmann and Jones, 1974; Dillon and Rigler, 1975; Jones and Bachmann, 1976; and Schindler, 1977).

Dillon and Rigler (1975) have applied their model to determining the extent to which development of recreational dwellings can be permitted while still maintaining the peak level of summer algal biomass (as chlorophyll *a*) below that selected by agencies managing a particular lake. We will attempt to utilize this model to assess the effects of future real estate development on Harding Lake. The phosphorus concentration is predicted using an equation derived from Vollenweider's (1969b) model

$$[P] = \frac{L}{\bar{z}(\sigma+\rho)} \qquad (1)$$

where

$[P]$ = predicted total phosphorus concentration
L = loading
$\bar{z}$ = mean depth
σ = sedimentation rate
ρ = flushing rate

The limited amount of nutrient analyses performed on aspects other than the water column at Harding Lake do not allow an accurate estimation of the phosphorus loading to the lake. Thus, the equation must be modified to separate the known present total phosphorus concentration from that which would be added by further cottage development. The equation becomes

$$[P] = \frac{K \cdot C/A}{\bar{z}(\sigma+1/R)} + [P_o] \qquad (2)$$

where

$[P]$ = predicted concentration of total phosphorus
K = annual total phosphorus output per cottage

C = number of additional cottage units
A = surface area of the lake
$\bar{z}$ = mean depth
σ = sedimentation rate
R = retention time
$[P_o]$= present average total phosphorus concentration

For this study K is calculated as 0.3×10^6 mg/cottage-year using the value of 0.8 kg/capita-year of Dillon and Rigler (1975), and the 0.3 capita-year/cottage-year obtained from Larson's (1974) study of cottage use at Harding Lake during 1973. A sedimentation rate of 0.65 was chosen, and the retention time of the lake has been estimated as approximately 70 years from the water budget calculations. The present average total phosphorus concentration is taken as 14 mg/m^3.

Using Equation 2, the effects on total phosphorus concentration of some future development possibilities at Harding Lake were calculated. Chlorophyll *a* values were then predicted from these total phosphorus concentrations (Dillon and Rigler, 1974). Finally, water clarity as Secchi depth values were predicted (Jones, J., and Bachmann, R., 1977, personal communication). These predictions are presented in Table 15.

TABLE 15: PREDICTED TOTAL PHOSPHORUS AND RESULTANT CHLOROPHYLL *a* CONCENTRATIONS AND SECCHI DEPTHS FOR SELECTED DEVELOPMENT POSSIBILITIES AT HARDING LAKE

Development	Additional Cottage Equivalents	Predicted total P (mg/m^3)	Predicted Chlorophyll *a* (mg/m^3)	Predicted Secchi depth (m)
1975	0	14.0	3.3	3.3
a cottage on every parcel	130	14.4	3.5	3.2
all cottages converted to year-round homes	1,119	22.2	6.5	2.2

Application of these models to Harding Lake may be questionable. With the nitrogen-to-phosphorus ratio at roughly 10:1, phosphorus may not be the limiting nutrient in Harding Lake as is assumed for these models. In addition, the fact that inorganic nitrogen forms are nearly undetectable during the growing season provides evidence that the lake may be nitrogen limited, in which case the models may lose their predictive ability.

It can be noted that the predicted chlorophyll *a* concentration of 3.3 mg/m^3 for the measured total phosphorus concentration of 14 mg/m^3 of 1975 was approximated by the values actually measured at about 2 mg/m^3 in early spring 1975 (Figure 16). During this under-ice chlorophyll *a* peak, a Secchi depth of 5 m was measured (Figure 17) which is close to the 3.3 m predicted.

The fact that Harding Lake has its peak algal biomass and productivity under the spring ice rather than in the summer may also make these models inapplicable. As pointed out above, however, these models seem to predict adequately the peak chlorophyll *a* concentration and resultant Secchi depths. The reduction in water clarity at peak algal biomass is not currently noticed by the general public because of the ice cover. Perhaps the greatest danger in future development on Harding Lake would be that nutrient additions might promote a shift in algal succession so that the peak growth would occur in summer. The resultant loss of water clarity (below the current summer Secchi depth of approximately 11 m) could be very noticeable and undesirable.

Vascular Aquatic Plants

A list of the submerged hydrophyte species found in Harding Lake during the summer of 1974 is presented in Table 16. One macroalga (*Chara* sp.) and one pteridophyte (*Isoetes muricata* var. *Braunii*) were found as well as a variety of angiosperms. Figure 23 presents a map of the plant beds and locates the starting points of the transects samples. Table 17 presents the biomass estimates for the samples that represented 100% cover of a single species. The transect data is included in Appendix Table A-4.

Using the transect percent cover data and the biomass estimates for 100% cover for each species, the biomass produced above the sediments was estimated for each of the major plant beds. The bed containing transect #1, which is $2 \times 10^5 m^2$ in extent, produced approximately 6400 kg of plant tissue

TABLE 16. THE SUBMERSED HYDROPHYTE SPECIES OF HARDING LAKE, ALASKA 1974

Chara sp.

Isoetes muricata var. *Braunii*

Sparganium angustifolium

Potamogeton filiformis

Potamogeton Freisii

Potamogeton gramineus

Potamogeton perfoliatus subsp. *Richardsonii*

Potamogeton praelongus

Glyceria borealis

Eleocharis acicularis

Ranunculus confervoides

Subularia aquatica

Myriophyllum sp.

Minor species:

Potamogeton natans

Juncus alpinus

Eleocharis palustris

Polygonum amphibium

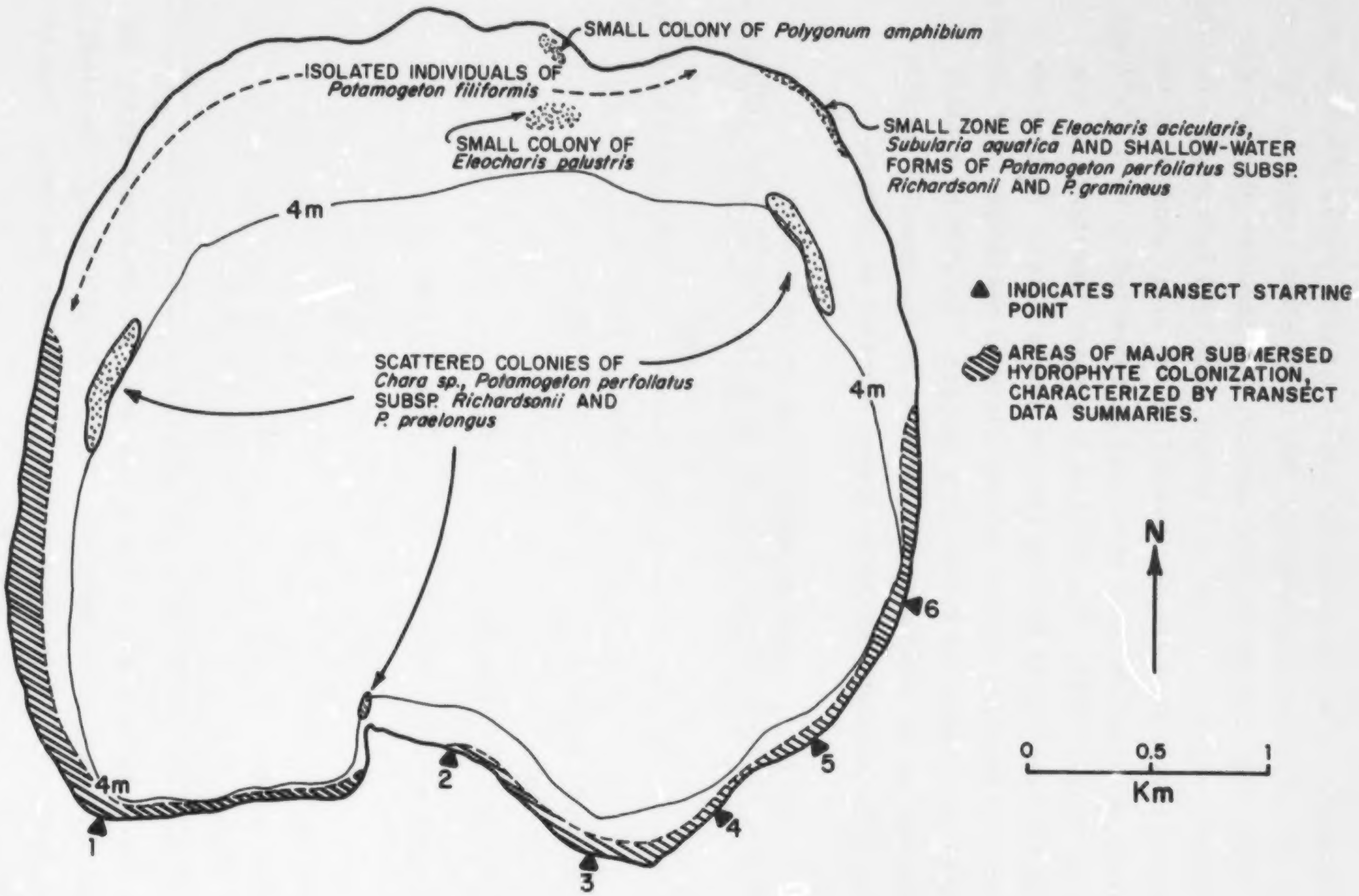

SMALL COLONY OF Polygonum amphibium
ISOLATED INDIVIDUALS OF Potamogeton filiformis
SMALL COLONY OF Eleocharis palustris
SMALL ZONE OF Eleocharis acicularis, Subularia aquatica AND SHALLOW-WATER FORMS OF Potamogeton perfoliatus SUBSP. Richardsonii AND P. gramineus
4m
4m
4m
SCATTERED COLONIES OF Chara sp., Potamogeton perfoliatus SUBSP. Richardsonii AND P. praelongus
1
2
3
4
5
6
▲ INDICATES TRANSECT STARTING POINT
▨ AREAS OF MAJOR SUBMERSED HYDROPHYTE COLONIZATION, CHARACTERIZED BY TRANSECT DATA SUMMARIES.
N
0
0.5
1
Km

FIGURE 23

PLANT DISTRIBUTION MAP. HARDING LAKE, 1975 (at 31.7 ± 37.6 g/m^2). The bed which included transects #2-#6, which has an area of 3 x $10^5 m^2$, produced approximately 6900 kg of plant tissue (at 23.1 ± 30.6 g/m^2). Thus, over the entire lake surface, the vascular plant production equaled approximately 1.35 g/m^2 dry weight submerged hydrophytes for the growing season of 1974. This can be compared to the algal production for 1975 estimated at 47.8 gm C/m^2/year which can be converted to 95.6 g/m^2/year dry weight algae (Lind, 1974). The relatively greater importance of the planktonic algal production in Harding Lake is demonstrated. However one aspect of primary production remains unknown since no measurements of benthic algal production were conducted during this project. In 1974 no benthic algae were observed to be growing on the surfaces of the vascular aquatic lants. During 1975, however, epiphytic growth appeared to be heavy.

TABLE 17. PLANT BIOMASS ESTIMATES FOR SAMPLES REPRESENTING 100% COVER OF A SINGLE SPECIES, HARDING LAKE, 1974

Species	g/m^2
Chara sp.	36.7 ± 19.0
Isoetes muricata var. *Braunii*	56.9 ± 58.5
Potamogeton filiformis	25.0
P. perfoliatus subsp. *Richardsonii* (shallow-water form $\leq$ 15cm)	121.0
P. perfoliatus subsp. *Richardsonii* (deep-water form $\geq$ 15cm)	28.4 ± 14.8
P. praelongus	91.5 ± 2.8
Clyceria borealis	92.6
Eleocharis acicularis	185 ± 93
Myriophyllum sp.	17.2 ± 6.9

Work on the vascular plants of this lake was also conducted during the summer of 1966 (LaPerriere and Robertson, 1973). Unfortunately, the plant beds were unmapped, thus it is not possible to calculate the annual production for that year.

Zooplankton

Very limited sampling of the zooplankton was conducted during this project. The major effort in this regard consisted of dry-weight measurements presented in Figure 24. The biomass present from season to season throughout a year is seen to vary by roughly a factor of ten and is probably concentrated in the upper 10 m of water. Limited data for May and June of 1973, not plotted because of lack of sufficient replicates, helps to indicate that the peak concentration is found in early August and the lowest concentration is found in March.

Counts of zooplankton taken with a large plexiglass trap near midnight and noon on August 5, 1974, (Table 18) show as is usually found that the zooplankton are distributed differently at different times of day. Of special note is the capture of *Leptodora kintii* at 10 m at night, a predator known to be phototactic and nocturnal.

TABLE 18. ZOOPLANKTON COUNTS. HARDING LAKE. AUGUST 5, 1974

	Individuals per m^3			
Sample Time:	0:00-2:00	0:00-2:00	12:00-14:00	12:00-14:00
Sample Depth:	2m	10m	2m	10m
Bosmina coregni	$2.2x10^3$	$3.3x10^3$	$2.1x10^3$	$1.5x10^3$
Ceratium sp.	$5.1x10^4$	$8.7x10^4$	$1.1x10^5$	$1.8x10^5$
Daphnia longiremus	$2.8x10^3$	$3.8x10^3$	$3.2x10^2$	$2.8x10^3$
Holopedium sp.	$5.7x10^2$	$2.4x10^2$	$2.4x10^2$	8.1x10
Kellicottia longispina	$1.4x10^3$	$2.6x10^3$	$2.5x10^3$	$2.5x10^3$
Keratella sp.	$2.4x10^2$	$8.1x10^2$	$1.6x10^2$	$1.3x10^3$
Leptodora kindtii		8.1x10		
Polyphemus pediculus		8.1x10		$1.6x10^2$
copepods	$1.2x10^4$	$1.4x10^4$	$1.4x10^3$	$3.9x10^3$
nauplii	$4.1x10^2$	$3.2x10^2$	$3.2x10^2$	$1.5x10^3$
unknowns	$2.4x10^2$	$8.1x10^2$	$4.0x10^3$	$9.0x10^3$

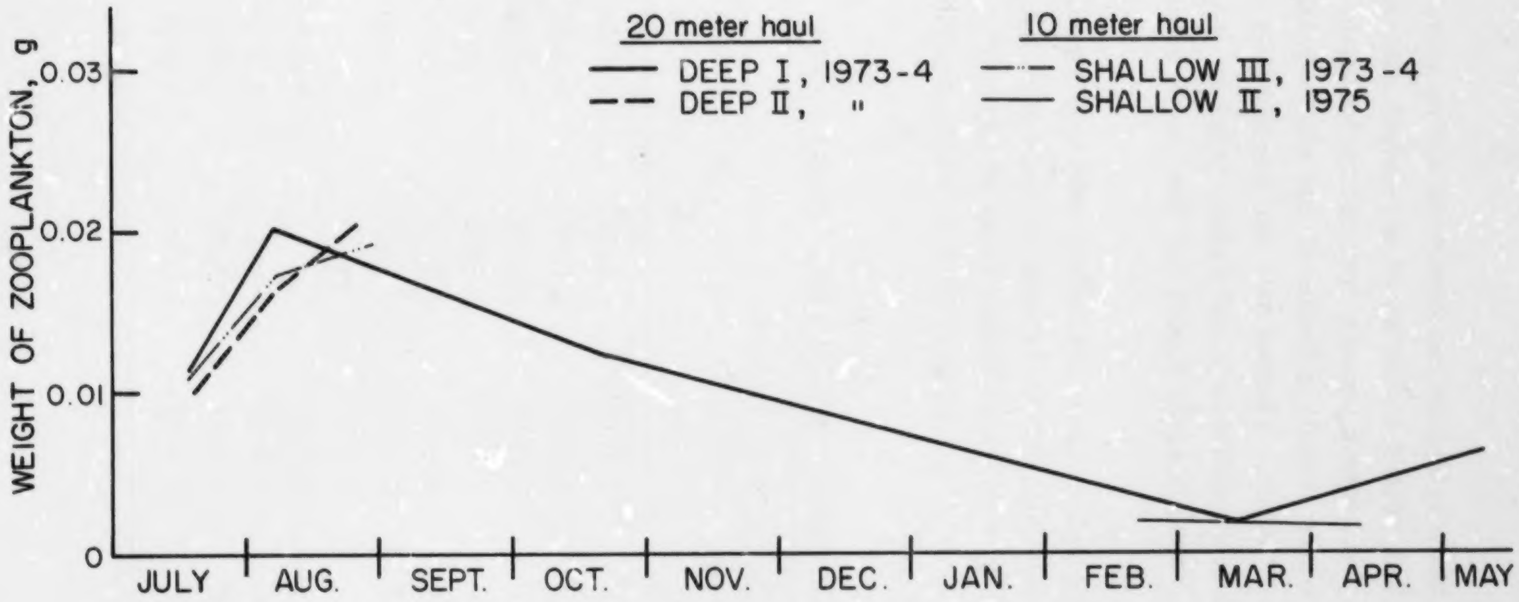


FIGURE 24

DRY WEIGHT OF ZOOPLANKTON CAPTURED. HARDING LAKE

Table 19 presents the zooplankters identified from Harding Lake during this project. An interesting phenomenon occurred several times when zooplankters were noted in high concentrations crawling over the plexiglass holders for the light and dark bottles of the algae experiments. The plankter involved was *Sida cristallina*. It is especially interesting to note that this occurred in deep water (at Deep Station I) since Brooks (1959) has reported "...they are never present in large numbers in the open water, nor are they likely to be found far out from the weedy margin."

TABLE 19. ZOOPLANKTON IDENTIFIED FROM HARDING LAKE

Cladocera	Copepoda
Bosmina coregoni	*Cyclops capitallatus*
Daphnia longiremus	*Cyclops* sp.
Eurycercus glacialis	*Diaptomus pribilofensis*
Holopedium gibberum	*Moraria mrazeki*
Leptodora kindtii	
Polyphemus pedicularis	Rotifera
Sida crystalina	*Kellicottia longispina*
	Keratella cochlearis

Fishes

While this project did not work with the fishes of the lake the following information has been provided us by the Alaska Department of Fish and Game.

Fish species contained in Harding Lake as of 11 February 1975:

Native:

Coregonus sardinella (Valenciennes) least cisco
Cottus cognatus (Richardson) slimy sculpin
Esox lucius (Linneaus) northern pike
Lota lota (Linneaus) burbot

Successfully Introduced:

Oncorhynchus kisutch (Walbaum) coho or silver salmon
Salvelinus namaycush (Walbaum) lake trout

Stocking and netting records are presented in Tables 20 and 21. The 1939 stocking of rainbow trout was unsuccessful. Recaptures of lake trout indicate that a breeding population has not been established.

Benthic Macroinvertebrates

Concurrent with the first two years of this project were two years of work on Alaskan lake benthos (LaPerriere, 1975) that treated samples from Harding Lake as well as other lakes in the state. Samples were taken by dredge the first summer and all organisms identified as far as possible (Tables 22 and 23). Sampling stations not identified in Figure 1 can be seen in Figure 25. During the second summer samples were taken both by dredge and by hand (by a diver) and the chironomids were separated and reared (Table 24).

The emphasis of the benthos work was on chironomids (nonbiting midges of the order Diptera), which have been relied upon in Europe as good indicators of the trophic state of lakes. Unfortunately the necessary taxonomic and ecological studies necessary to designate indicator chironomids in the Nearctic are not nearly complete. The first major paper on this subject has just been published (Saether, 1975) tabulating chironomid species and their distribution across the trophic spectrum. Of the chironomids of Harding Lake which have been identified to species, only one, *Monodiamesa bathyphila* (Kieff.), appears in Saether's tables. He believes it to be restricted to the oligotrophic situation in the Nearctic; however, it is also found in mesotrophic lakes in the Palearctic.

Enteric Bacteria

During the summer of 1973 (May-September) a thesis study was conducted relative to the water quality and pollution control at Harding Lake (Larson, 1974). This study, in the form of a graduate student thesis, included an evaluation of the lake water sanitary bacteriology in addition to a survey of sanitary facilities located at the lake. The objectives of the study were to characterize the shore land development at Harding Lake, to investigate the water supply and solid waste and sewage disposal practices, and to determine if Harding Lake was being contaminated to an extent that might limit recreational activities.

TABLE 20. FISH-STOCKING HISTORY. HARDING LAKE

Date Stocked	Species	Total Number	Per Kg	Per Hectare	Source
1939	RT[1]	No good records			Forest Service
	LT[2]	No good records			Forest Service
1956-1965	RT	125,000			ADF&G
1963	LT	252 adult			ADF&G
1965	LT	235 adult			ADF&G
December 1965	LT	88,000 eyed eggs (75,000 hatched)			ADF&G
July 1967	LT	31,200 fingerling			ADF&G
July 1968	SS[3]	375,800 fingerling			ADF&G
July 1969	SS	338,500 fingerling			ADF&G
July 1971	SS	232,800 fingerling	640	217	ADF&G

[1] RT = rainbow trout, *Salmo gairdneri*

[2] LT = lake trout, *Salvelinus namaycush*

[3] SS = silver salmon, *Onchorhynchus kisutch*

(Information from Alaska Department of Fish and Game [ADF&G], 1974).

TABLE 21. NETTING RECORDS. HARDING LAKE

Date	Species	Fish Netted	Length (mm) Range	Length (mm) Mean	Net Hours	Frequency	Age Class	Percent Composition
Sep-Oct 1959**	NP[1]	35	* -965	533	566	.06		
Sep 1960	LCi[2]	40	* -305	201		.07		
	LT[3]	1		991		.002		
Jun 1961	NP	24			18.5	1.3		
Oct 7-8, 1962	NP	2			31	.06		
	LCi	2				.06		
1963	No test netting done							
1964**	NP	4	490-750					
	LCi	6	185-290					
Sep 1, 1964	NP	10	356-813	465		.08		
	LT	5	478-767	650		.04		
Oct 13, 1964	NP	4	498-838	592		.08		
	LCi	6	188-295	218		.12		
Sep 10, 1965	NP	6	254-617	480		.06		
	LCi	5	191-218	206		.05		
Oct 6, 1965	LT	3	559-597	574		.03		
	NP	2	506-597	551		.02		
	LCi	70	127-279	203		.73		
Sep 13, 1966	LT	6	432-635	523		.03		
	NP	16	318-615	465		.08		
	LCi	23	185-216	201		.12		
	BB[4]	2	480-559	518		.01		

(continued)

TABLE 21 (continued)

Date	Species	Fish Netted	Length (mm)		Net Hours	Frequency	Age Class	Percent Composition
			Range	Mean				
1967	No test netting done							
Sep 1968	LT	4	533-685	633	290	.014		
	NP	20				.07		
	LCi	119				.41		
	BB	2				.006		
Jun 5, 1969	NP	6	440-705	562		.13		
Jun 6, 1969	NP	9	390-715	530		.18		
Jun 26, 1969	NP	8	371-621	480		.07		
	LCi	5	152-175	164		.05		
Aug 1970**	LT	6	393-821	691	352	.02		
	NP	12	485-690	591		.04		
	BB	9	375-695	462		.03		
	LCi	392	120-235			1.11		
Aug 13, 1971	SS[5]	2	95-117		24	.08		
	LT	1	540			.04		
	NP	1	675			.04		
	LCi	6	118-235			.25		
Jun 8-21,1972	BB	9	509-670	580		.04		
	NP	11	511-634	584		.05		
	LCi	22	129-246	157		.10		
	LT	1	561			.01	V	
Sep 8, 1972	NP	31	173-707	541		.55		
	LT	1	588			.02	V	
	SS	8	201-250	228		.13	I	

(continued)

TABLE 21 (continued)

Date	Species	Fish Netted	Length (mm) Range	Length (mm) Mean	Net Hours	Frequency	Age Class	Percent Composition
May 22- Aug 10, 1973	LT	8	630-730	696.8	419.5	.02		3
	NP	148	255-830	515.9		.35		57
	LCi	76				.18		29
	SS	25	145-155	150		.06		10
	BB	2	580-665	662.5		.005		1
Aug 6-9,1974	NP	45	140-635	449.5	576	.08		51
	LT	2	570-730	650		.003		2
	LCi	28	120-200	155.9		.05		32
	BB	10	380-655	474		.02		11
	SS	3	335-395	361.7		.005		4
Nov 22-Dec 6, 1974	NP	7	140-580	395.7	552	.01		21
	LT	2	495-680	587.5		.004		6
	BB	17	380-670	580.9		.03		50
	SS	8	285-410	359.4		.01		23

[1] NP - northern pike, *Esox lucius*
[2] LCi- least cisco, *Coregonus sardinella*
[3] LT - lake trout, *Salvelinus namaycush*
[4] BB - burbot, *Lota lota*
[5] SS - silver salmon, *Oncorhynchus kisutch*
*indicates data not provided
**date unknown
(Information from Alaska Department of Fish and Game, 1974.)

TABLE 22. BENTHIC MACROINVERTEBRATES. HARDING LAKE PROFUNDAL AND SUBLITTORAL STATIONS. JULY 24, 1973

		Organism		
Station	Depth	Group	Identification	Number
DEEP STATION I				
Sample 1	42 m	cl.[1]	*Pisidium* sp.	3
		w.[2]	*Peloscolex* sp.	1
Sample 2	42 m	c.[3]	*Phaenopsectra* sp.	1
		cl.	*Pisidium* sp.	1
Sample 3	42 m	c.	*Phaenopsectra* sp.	1 ecdysis
		w.	*Peloscolex* sp.	2
			unidentified tubificid	
DEEP STATION II				
Sample 1	20 m	c.	*Phaenopsectra* sp.	4
		cl	*Pisidium* sp.	4
		w.	*Peloscolex* sp.	6
Sample 2	20 m	c.	*Phaenopsectra* sp.	5
		w.	*Peloscolex kurankovi*	4
Sample 3	20 m	c.	*Phaenopsectra* sp.	5
			Phaenopsectra sp.	1 ecdysis
		w.	*Peloscolex kurankovi*	1
SHALLOW STATION II				
Sample 1	18 m	w.	*Peloscolex* sp.	1
			unidentified tubificid	1
Sample 2	18 m	c.	*Monodiamesa bathyphilia*	1 ecdysis
			Procladius sp.	2
			Protanypus sp.	1
		cl.	*Pisidium* sp.	5

[1]cl.-clams, [2]w.-worms, [3]c.-chironomids

(continued)

TABLE 22 (continued)

Station	Depth	Organism Group	Identification	Number
Sample 3	18 m	cl.	*Pisidium* sp.	3
SHALLOW STATION III				
Sample 1	16 m	c.	*Chironomus* sp. (pupa)	1
			Monodiamesa bathyphilia	3 ecdyses
			Phaenopsectra sp.	1
			Procladius sp.	3
			Procladius sp.	2 ecdyses
			Protanypus sp.	2
			Protanypus sp.	3 ecdyses
			Stictochironomus rosenschöldi	1 ecdysis
		w.	*Peloscolex* sp.	1
Sample 2	16 m	c.	*Protanypus*	2
Sample 3	16 m	c.	*Monodiamesa bathyphilia*	1 ecdysis
			Protanypus sp.	2
			Protanypus sp.	6 ecdyses
		cl.	*Pisidium* sp.	8
		s.[4]	*Lymnaea* sp.	1
		w.	unidentified tubificid	1
SHALLOW STATION IV				
Sample 1	11 m	c.	*Monodiamesa bathyphilia*	1
			Monodiamesa bathyphilia	6 ecdyses
			Procladius sp.	1
			Protanypus sp.	2 ecdyses
			Phaenopsectra sp.	1 ecdysis
		s.	*Lymnaea* sp.	9
		w.	*Peloscolex* sp.	1

[4] s.-snails.

(continued)

TABLE 22 (continued)

		Organism		
Station	Depth	Group	Identification	Number
SHALLOW STATION IV				
Sample 2	11 m	c.	*Procladius* sp.	3
			Protanypus sp.	1
		cl.	*Pisidium* sp.	2
		cd.[5]	unidentified calanoid	4
		m.[6]	unidentified	1
		s.	*Lymnaea* sp.	5
		w.	*Peloscolex* sp.	1
Sample 3	11 m	c.	*Phaenopsectra* sp.	1
		cl.	*Pisidium* sp.	1
		w.	*Peloscolex* sp.	3
			unidentified tubificid	1

[5] cd.-copepods, [6] m.-mites

TABLE 23. BENTHIC MACROINVERTEBRATES. HARDING LAKE LITTORAL STATIONS. AUGUST 17, 1973

		ORGANISM		
Station	Depth (m)	Group	Identification	Number
7	0.75	a.[1]	*Hyalella azteca*	1
		ce.[2]	*Palpomyia* sp.	7
			unidentified adult	1
		cl.[3]	*Pisidium* sp.	15
		e.[4]	unidentified larva	1
		l.[5]	*Dina* sp.	1
		n.[6]	unidentified	1
		s.[7]	*Lymnaea*	2
			Cyrallus sp. (type 2)	1
		t.[8]	unidentified Beraeidae	1
			unidentified Limnephilidae	1
			Mystacides sp.	1
11 (Sample 1)	1.0	a.	*Hyalella azteca*	22
		c.[9]	*Clinotanypus* sp.	1
		cl.	*Pisidium* sp.	16
		l.	*Dina* sp.	1
		s.	*Lymnaea* sp.	1
			Gyrallus (type 1)	3
			Gyrallus (type 2)	2
11 (Sample 2)	1.0	a.	*Hyalella azteca*	15
		ne.[10]	unidentified	1
		s.	*Gyrallus* sp.	1
		w.[11]	*Peloscolex* sp.	13

[1]a.-amphipods, [2]ce.-ceratopogonids (flies), [3]cl.-clams, [4]e.-empidids (flies), [5]l.-leeches, [6]n.-nematomorphs, [7]s.-snails, [8]t.-trichopterans, [9]c.-chironomids (flies), [10]ne.-nematodes, [11]w.-worms

(continued)

TABLE 23 (continued)

		ORGANISM		
Station	Depth (m)	Group	Identification	Number
16	6.0	c.	*Monodiamesa bathyphilia*	1 ecdysis
			Procladius sp.	3
			Stempellina sp.	1
		cl.	*Pisidium* sp.	5
		t.	*Mystacides* sp.	1
		w.	*Peloscolex* sp.	15
			unidentified tubificid	3
18	1.0	a.	*Hyalella azteca*	7
		c.	*Demichryptochironomus* sp.	1
			Tanytarsus sp.	
		ce.	unidentified	1
		cl.	*Pisidium* sp.	15
		cd.[12]	unidentified	1
		ta.[13]	*Chryspos* sp.	1
		w.	*Peloscolex* sp.	5
			unidentified tubificid	10
21	*1.5	a.	*Hyalella azteca*	53
		ce.	*Leptoconops* (adult)	1
			Palpomyia sp.	2
		c.	*Dicrotendipes* sp.	8
			Microtendipes sp.	1
			Potthastia sp.	1
			Procladius sp.	1
			Parachironomus sp.	2
			Stempellina sp.	28
			Tanytarsus sp.	1

*this is a composite of two dredge samples

[12] cd.-copepods, [13] ta.-tabanids (flies)

(continued)

TABLE 23 (continued)

Station	Depth (m)	ORGANISM Group	 Identification	 Number
		cl.	*Pisidium* sp.	36
		l.	*Dina dubia*	1
		m.[14]	unidentified	1
		s.	*Gyrallus* (type 1)	2
			Gyrallus (type 2)	4
			Lymnaea sp.	1
		t.	*Mystacides* sp.	2
			unidentified pupa	1
		w.	*Peloscolex* sp.	15
			unidentified tubificids	20
23	1.3	a.	*Hyalella azteca*	49
		c.	*Harnischia* sp.	1
		cl.	*Pisidium* sp.	5
		l.	*Dina* sp.	4
		ma.[15]	*Paracloedes* sp.	2
		m.	unidentified	1
		t.	unidentified Beraeidae	1
		w.	*Peloscolex* sp.	32
			unidentified Lubriculidae incomplete	6
			unidentified tubificids	6
25	1.0	a.	*Hyalella azteca*	18
		s.	*Lymnaea* sp.	1
			Gyrallus (type 1)	1
			Gyrallus (type 2)	3
		t.	unidentified Beraeidae	1
			Trianodes sp.	2
		w.	unidentified Lumbriculidae	2

[14] m.-mites, [15] ma.-mayflies

(continued)

TABLE 23 (continued)

		ORGANISM		
Station	Depth (m)	Group	Identification	Number
27	1.0	a.	*Hyalella azteca*	12
		c.	*Ablabesmyia*	1
		m.	*Paracloedes*	2
		n	unidentified	1
		s.	*Gyrallus* (type 2)	3
			Lymnaea sp.	1
		t.	unidentified Beraeidae	1
		w.	*Peloscolex* sp.	1
30	0.5	a.	*Hyalella azteca*	10
		ce.	*Palpomyia* sp.	1
		c.	*Cryptochironomus digitatus*	4
			Stictochironomus rosenschöldi	6
		cl.	*Pisidium* sp.	2
		ma.	*Paracloeodes* sp.	2
		s.	*Physa* sp.	1
			Gyrallus (type 1)	5
		t.	unidentified Beraeidae	1
			Trianodes sp.	1
		w.	unidentified Lumbriculidae	1
			unidentified tubificid	2
35	1.3	a.	*Hyalella azteca*	6
		ce.	*Palpomyia* sp.	3
		c.	*Polypedium* sp.	1
			Stempellina sp.	1
		cl.	*Pisidium* sp.	1
		l.	*Dina* sp.	1
		m.	unidentified	1

(continued)

TABLE 23 (continued)

Station	Depth (m)	Group	ORGANISM Identification	Number
		s.	*Lymnaea*	2
			Gyrallus (type 2)	5
		ta.	*Chrysops* sp.	1
		t.	unidentified Beraeidae	1
		w.	*Peloscolex* sp.	7
			unidentified tubificid	4

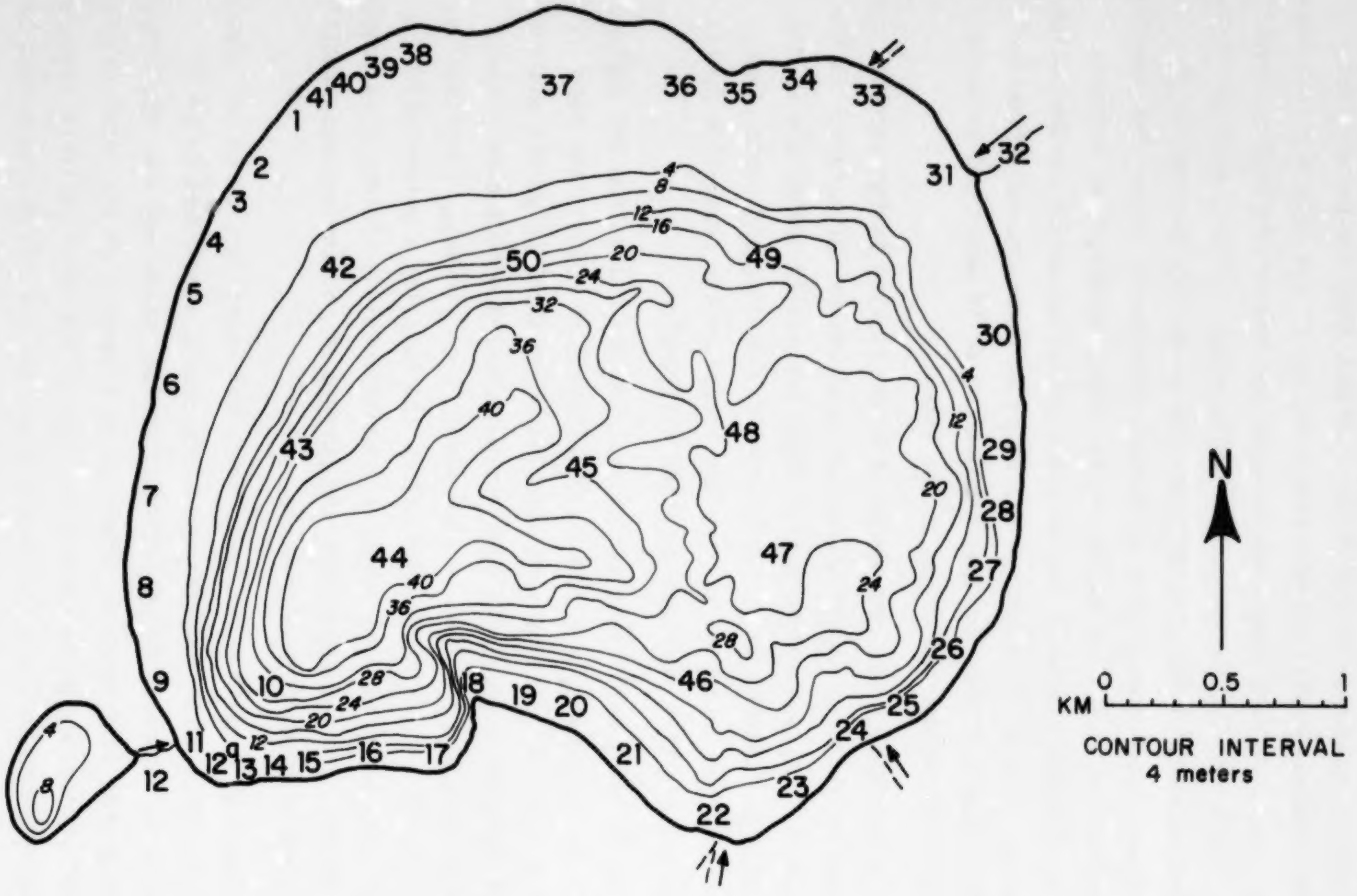
TABLE 24. CHIRONOMIDS REARED FROM HARDING LAKE, 1974

Tanypodinae

- *Clinotanypus pinguis* (Loew)
- *Procladius (Psilotanypos) bellus* (Loew)
- *Procladius (Procadius) freemani* (Subl.)

Chironominae

- *Einfeldia pagana* (Meig.)
- *Parachironomus* sp. n. near *swammerdami*
- *Chironomus* cf. *hyperboreus* (Staeg.)
- *Chironomus* sp. n.
- *Chironomus* sp. (female) probably different from the two above.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8
12
16
20
24
28
32
36
40
N
0
0.5
1
KM
CONTOUR INTERVAL
4 meters

FIGURE 25
MORPHOMETRIC MAP OF HARDING LAKE WITH SAMPLING STATIONS FOR BENTHOS AND BACTERIOLOGICAL SAMPLING INDICATED.

Justification for the study was based on two reasons: (1) Coliform bacteria studies conducted by the State of Alaska from the period 1966 through 1971 indicated that serious contamination of the lake may have been occurring. Coliform data ranged up to 4,500 per 100 ml recorded on August 30, 1966. Additionally, during July of 1971, total coliform analyses indicated a high value of 1,200 coliforms per 100 ml and the Department of Health and Social Services, State of Alaska, considered closing the lakefront to recreational use. (2) During the early 1970s, Harding Lake property owners expressed concern about the possible pollution and/or contamination of Harding Lake. Some of this concern was based on deterioration of aesthetic values, which stemmed from improper disposal of solid waste and unsubstantiated reports of sewage pollution of the lake.

This investigation was considered of high priority in the study of the lake because of the high degree of recreational use of the waters. In the Fairbanks area, only two moderate size lakes are easily accessible by the road system and within 80 km of the community - Harding and Birch Lakes. Harding Lake is the larger of the two and closer to the population center of Fairbanks, therefore it receives a higher utilization.

The bacteriological investigation included the collection and analyses of samples for standard plate counts, total coliform counts, and fecal coliform counts. Sample stations were established on the lake waters and included near-shore stations, some lying over bottom muds and others over gravel, pelagic stations, and stations located along inlet streams. Additionally, vertical profile samples were taken within the lake for a determination of mixing patterns and potential subsurface contamination. Intensified sampling occurred during July and August for the purpose of monitoring water quality during period of high recreational use.

A summary of data from the bacteriological investigation is included in Tables 25 and 26. Data from standard plate counts were found to be of little value in detection of pollution or contamination and are, therefore, not included with this summary. Table 25 is a summary of the fecal coliform information collected for Harding Lake. All of the fecal coliform tests were within the recommended limit (below 200 organisms per 100 ml) suggested by

TABLE 25. STATISTICAL SUMMARY OF FECAL COLIFORM RESULTS.[1] HARDING LAKE. 1973

Date	Number of Samples	Mean	Standard Deviation	Range
		All Lake Stations		
May 30	29	0		
June 25	48	0.2	0.9	0- 5
July 17	49	0.2	0.6	0- 2
August 7	44	1.0	2.1	0- 8
August 28	49	0.3	1.0	0- 6
September 3	49	0.4	2.6	0-18
September 5	49	0.1	0.9	0- 6
		Near-Shore Stations		
May 30	25	0		
June 25	38	0.2	0.9	0- 5
July 17	39	0.2	0.6	0- 2
August 7	39	1.1	2.2	0- 8
August 28	39	0.4	1.1	0- 6
September 3	39	0.5	2.9	0-18
September 5	39	0.2	1.0	0- 6
		Pelagic Stations		
May 30	4	0		
June 25	10	0.2	0.6	0- 2
July 17	10	0		
August 7	5	0		
August 28	10	0		
September 3	10	0		
September 5	10	0		

---

[1] Fecal Coliforms/100 ml.

TABLE 26. STATISTICAL SUMMARY OF TOTAL COLIFORM RESULTS.[1] HARDING LAKE. 1973

Date	Number of Samples	Mean	Standard Deviation	Range
		All Lake Stations		
May 30	29	3.6	7.4	0- 39
June 25	48	6.1	4.8	0- 21
July 17	49	9.3	9.8	0- 32
August 7	44	6.5	9.1	0- 38
August 28	49	318.2	225.7	2- 776
September 3	49	297.5	248.6	30-1,480
September 5	49	166.5	93.7	20- 390
		Pelagic Stations		
May 30	5	1.2	1.6	0- 3
June 25	10	6.2	3.4	2- 13
July 17	10	3.8	9.4	0- 30
August 7	5	2.0	2.8	0- 6
August 28	10	535.6	102.4	444- 766
September 3	10	304.0	84.9	190- 460
September 5	10	223.0	66.8	130- 330
		Near-Shore Stations		
May 30	24	4.1	8.1	0- 39
June 25	38	6.1	5.1	2- 21
July 17	39	10.8	9.5	0- 32
August 7	39	7.0	9.5	0- 38
August 28	39	262.5	215.0	0- 754
September 3	39	295.9	276.3	30-1,480
September 5	39	152.0	94.8	20- 390

[1] Total Coliforms/100 ml

(continued)

TABLE 26 (continued)

Date	Number of Samples	Mean	Standard Deviation	Range
Mud Bottom Stations				
May 30	16	5.1	9.7	0- 39
June 25	23	8.3	5.3	0- 21
July 17	24	14.6	9.7	0- 32
August 7	24	5.7	8.9	0- 36
August 28	24	369.8	196.8	8- 754
September 3	24	397.5	292.7	102-1,480
September 5	24	185.0	83.8	54- 390
Gravel Bottom Stations				
May 30	8	2.1	1.9	0- 5
June 25	15	2.6	1.9	0- 7
July 17	15	4.7	5.2	0- 14
August 7	15	9.2	10.3	0- 38
August 28	15	90.8	102.3	2- 348
September 3	15	135.7	150.2	30- 536
September 5	15	99.2	89.4	20- 320

the National Technical Advisory Committee (1968) as a standard for recreational water. There was no single sample location or area where fecal coliforms were consistently detected and thus it is felt that fecal contamination was sporadic and of a local nature. Due to the relatively low fecal coliform values, it is suggested that little, if any, domestic sewage was entering Harding Lake from the developed area.

Total coliform data is presented in Table 26 as a summary. Total coliform analyses showed that Harding Lake complied with State of Alaska criteria for recreational waters during the study period. Only one of over 300 total coliform analyses exceeded the criterion of 1,000 total coliforms per 100 ml of sample. Total coliform results were widely variable but again it was concluded that little or no domestic sewage was contaminating the lake from its developed area. Based on lack of correlation with the recreational usage data, it was apparent that the human-use level at Harding Lake had no adverse effect on total coliform number. Although the results of the vertical distribution study were inconclusive, it appeared that no significant increase in bacterial numbers occurred with depth.

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APPENDIX

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A-1 Ammonia Nitrogen Concentration (μg/l as N), Harding Lake--1973 . . 116

A-2 Chlorophyll *a* Concentrations, Deep and Shallow Stations, Harding Lake--1973-1974. 118

A-3 Chlorophyll *a* and Phaeopigment Concentrations, Shallow Stations, Harding Lake--1975 120

A-4 Plant Transect Data Summary, Harding Lake--1974. 123

TABLE A-1. AMMONIA NITROGEN CONCENTRATION (μg/l as N). HARDING LAKE. 1973

Deep Station I

Depth (m)	Apr 26	Jun 17	Jul 16	Aug 6	Oct 23	Dec 4
1		5	15	10	11	
2		<2			10	14
4		<2			11	10
5	20	<2				9
10	5	<2			11	6
15		<2				6
20	5	<2				6
25						6
30						3
40	5					

Deep Station II

Depth (m)	Apr 26	Jun 17
1		<2
2		<2
3	3	
4		<2
5	2	
10	2	<2
20	2	3

Shallow Station II

Depth (m)	Apr 26	Jun 17	Jul 16
1		4	21
		<2	
4		<2	
5	10		
6		<2	
8		4	
10	6		

(continued)

TABLE A-1 (continued)

Shallow Station III				Shallow Station IV		
Depth (m)	Apr 26	Jun 17	Jul 16	Depth (m)	Apr 26	Jun 17
1		2	25	1		<2
2		3		2		
4		3		4		
5	5			5	12	
6		2		6		
8		<2		8		<2
10	8	4		10	6	2
15	5	<2				

TABLE A-2. CHLOROPHYLL *a* CONCENTRATIONS*
HARDING LAKE. DEEP AND SHALLOW STATIONS. 1973-1974

DEEP STATION I

August 6, 1973		August 27, 1973		October 18, 1973	
Depth (m)	Concentration (mg/m^3)	Depth (m)	Concentration (mg/m^3)	Depth (m)	Concentration (mg/m^3)
0	0.68 ± 0.04	0	0.67 ± 0.06	0	0.97 ± 0.04
2	0.84 ± 0.07	2	0.72 ± 0.04	2	1.00 ± 0.03
4	1.00 ± 0.24	4	0.74 ± 0.02	4	1.07 ± 0.08
6	0.77 ± 0.06	6	0.74 ± 0.01		
8	1.12	8	0.88 ± 0.06		
10	0.84	10	0.98 ± 0.10		

December 4, 1973		March 15, 1974		April 16, 1974	
Depth (m)	Concentration (mg/m^3)	Depth (m)	Concentration (mg/m^3)	Depth (m)	Concentration (mg/m^3)
0	0.41 ± 0.04	2	1.92 ± 0.15	2	1.92 ± 0.15
2	0.50	4	0.88 ± 0.03	4	2.27
4	0.53 ± 0.07	6	0.61 ± 0.11	6	1.35 ± 0.02
6	0.55 ± 0.00	8	0.45 ± 0.00	8	0.79 ± 0.03
8	0.75	10	0.42	10	0.56 ± 0.02
10	0.73 ± 0.04	12	0.35 ± 0.01	12	0.45 ± 0.00
15	0.54 ± 0.01	14	0.28 ± 0.03	14	0.42
20	0.39 ± 0.08	16	0.27 ± 0.01	16	0.32 ± 0.04
25	0.39 ± 0.01	20	0.29 ± 0.04	20	0.24
30	0.34 ± 0.01	25	0.29 ± 0.04	25	0.30 ± 0.00
		30	0.32 ± 0.05	30	0.39 ± 0.02
		35	0.25 ± 0.04	35	0.30 ± 0.01

---

*calculated according to Strickland and Parsons (1965)

(continued)

TABLE A-2 (continued)

SHALLOW STATION II

August 27, 1973		March 15, 1974	
Depth (m)	Concentration (mg/m^3)	Depth (m)	Concentration (mg/m^3)
0	0.66	2	1.88 ± 0.04
2	0.86 ± 0.15		
4	0.91		
6	0.74 ± 0.01		
8	0.75 ± 0.01		
10	0.66		

SHALLOW STATION III		SHALLOW STATION IV			
August 6, 1973		March 15, 1974		April 6, 1974	
Depth (m)	Concentration (mg/m^3)	Depth (m)	Concentration (mg/m^3)	Depth (m)	Concentration (mg/m^3)
0	0.65 ± 0.17	2	0.39 ± 0.06	2	0.83
2	0.81 ± 0.13			3	2.24 ± 0.24
4	0.74 ± 0.28				
6	0.99 ± 0.08				
8	0.89 ± 0.09				
10	1.15 ± 0.09				

TABLE A-3. CHLOROPHYLL *a* AND PHAEOPIGMENT CONCENTRATIONS* HARDING LAKE. SHALLOW STATIONS. 1975

Shallow Station I

Depth (m)	May 29		June 19	
	Chlorophyll *a* (mg/m^3)	Phaeophytin (mg/m^3)	Chlorophyll *a* (mg/m^3)	Phaeophytin (mg/m^3)
1	1.49		0.52	
2	1.44		0.61	
3	1.84		0.67	
4	2.09		0.78	
	July 16		July 30	
	Chlorophyll *a* (mg/m^3)	Phaeophytin (mg/m^3)	Chlorophyll *a* (mg/m^3)	Phaeophytin (mg/m^3)
1	0.65		0.65	
2	0.70		0.52	.008
3	0.42		0.56	
4	0.68		0.69	
	August 14		August 26	
	Chlorophyll *a* (mg/m^3)	Phaeophytin (mg/m^3)	Chlorophyll *a* (mg/m^3)	Phaeophytin (mg/m^3)
1	0.79		0.62	
2	0.68		0.43	0.30
3	0.39	0.71	0.57	0.09
4	0.59	0.14	0.81	

*calculated according to Golterman (1969)

(continued)

TABLE A-3 (continued)

	October 13	
Depth (m)	Chlorophyll *a* (mg/m^3)	Phaeophytin (mg/m^3)
1	0.65	0.53
2	0.82	0.01
3	0.57	0.09
4	0.91	

Shallow Station II

	February 22		April 11	
Depth (m)	Chlorophyll *a* (mg/m^3)	Phaeophytin (mg/m^3)	Chlorophyll *a* (mg/m^3)	Phaeophytin (mg/m^3)
1			2.73	
2	0.79		2.18	
4	0.31		2.22	
6	0.07	0.18	0.55	0.03
8	0.00	0.09	0.34	0.02
10	0.53		0.31	0.03
12	0.14	0.01	0.57	

Shallow Station IV

	March 22		May 3	
Depth (m)	Chlorophyll *a* (mg/m^3)	Phaeophytin (mg/m^3)	Chlorophyll *a* (mg/m^3)	Phaeophytin (mg/m^3)
1	0.65		1.23	
2	0.71		1.30	
3	0.66		1.43	

(continued)

TABLE A-3 (continued)

Shallow Station V

Depth (m)	June 19		July 16	
	Chlorophyll *a* (mg/m^3)	Phaeophytin (mg/m^3)	Chlorophyll *a* (mg/m^3)	Phaeophytin (mg/m^3)
1	0.63		0.64	
2	0.80		0.32	0.33
3	0.75		0.84	

Depth (m)	July 30		August 14	
	Chlorophyll *a* (mg/m^3)	Phaeophytin (mg/m^3)	Chlorophyll *a* (mg/m^3)	Phaeophytin (mg/m^3)
1	0.51	.004	0.76	
2	0.69		0.73	
3	0.81		0.73	0.08

Depth (m)	August 26		October 13	
	Chlorophyll *a* (mg/m^3)	Phaeophytin (mg/m^3)	Chlorophyll *a* (mg/m^3)	Phaeophytin (mg/m^3)
1	0.24	0.46	0.79	0.06
2	0.64	0.15	0.44	0.45
3	0.75		0.75	0.17

TABLE A-4. PLANT TRANSECT DATA SUMMARY. HARDING LAKE. 1974

Distance From Shore (m)	Depth (cm)	Species	Height (cm)	Cover %
		Transect 1		
5	5	*G. borealis*	∿ 40	20
		E. acicularis	2	40
10	25	*G. borealis*	∿ 40	30
		P. filiformis	6-8	20
		I. muricata	5	5
15	35	*E. acicularis*	6	5
		I. muricata	5	80
		P. filiformis	10	5
20	50	*E. acicularis*	2	80
		I. muricata	3	20
		P. filiformis	6-8	20
25	60	*P. Richardsonii*	10	5
		E. acicularis	1	10
		I. muricata	3	20
30	80	*I. muricata*	1	20
35	90	*I. muricata*	6	70
40	100	*E. acicularis*	2	5
		I. muricata	5	25
45	120	*I. muricata*	6	50
		E. acicularis	2	5
50	140	*I. muricata*	3	25
55	160	*I. muricata*	3	40
60	180	*I. muricata*	4	20
65	190	*I. muricata*	4	30
70	200	*I. muricata*	4	20
75	200	*I. muricata*	2	5
80	230	*P. Richardsonii*	40	20
85	250	*P. Richardsonii*	60	50
90	270	*P. Richardsonii*	60	50
95	290	*P. Richardsonii*	30	20
100	310	*Chara* sp.	6	50

(continued)

TABLE A-4 (continued)

Distance From Shore (m)	Depth (cm)	Species	Height (cm)	Cover %
		Transect 2		
5	58	*I. muricata*	2	60
		P. Richardsonii	22	5
		S. angustifolium	9	negl.
10	95	*I. muricata*	3	80
		P. gramineus	12	10
15	120	*E. acicularis*	3	40
		I. muricata	3	50
		P. gramineus	50-120	5
		P. Richardsonii	20	negl.
20	140	*I. muricata*	4	20
		P. gramineus	20-40	15
25	120	*I. muricata*	5	5
		P. gramineus	50	5
30	130	*I. muricata*	5	5
		Transect 3		
5	80	*S. angustifolium*	60	20
10	35	*S. angustifolium*	∿100	50
15	45	*I. muricata*	4	20
		P. filiformis	10	80
		S. angustifolium	∿100	80
20	60	*I. muricata*	5	50
		P. filiformis	15	10
		P. gramineus	20	5
		S. angustifolium	∿100	10
25	70	*I. muricata*	4	40
		P. gramineus	20	5
30	80	*I. muricata*	5	100
35	88	*I. muricata*	5	100
		P. gramineus	40	negl.
40	110	*I. muricata*	4	100
45	130	*I. muricata*	5	70

(continued)

TABLE A-4 (continued)

Distance From Shore (m)	Depth (cm)	Species	Height (cm)	Cover %
50	150	*I. muricata*	5	40
		P. Richardsonii	100	50
55	160	*I. muricata*	5	30
		P. Richardsonii	100	50
60	170	*Myriophyllum* sp.	50	30
		P. Richardsonii	100	50
65	195	*I. muricata*	6	20
		Myriophyllum sp.	60	30
		P. Richardsonii	100	40
		Ranunculus sp.	6	10
70	210	*Myriophyllum* sp.	30	50
		P. Richardsonii	50	20
75	240	*Myriophyllum* sp.	60	80
		P. Richardsonii	150	negl.
80	250	*Myriophyllum* sp.	50	60
85	280	*Myriophyllum* sp.	40	20
90	300	*Myriophyllum* sp.	20	negl.
		P. Richardsonii	200	60
95	320	*Chara* sp.	6	negl.
		Myriophyllum sp.	20	negl.
100	340	*Myriophyllum* sp.	20	negl.
		Transect 4		
5	6	*S. angustifolium*	∿ 60	80
		S. aquatica	3	40
10	18	*E. acicularis*	2	10
		P. gramineus	12	10
		S. fluctuans	∿ 60	50
		S. aquatica	2	20
15	25	*I. muricata*	4	negl.
		P. gramineus	15	5
		P. Richardsonii	20	negl.
		S. augustifolium	∿100	50
20	32	*E. acicularis*	2	50
		P. Richardsonii	20	50

(continued)

TABLE A-4 (continued)

Distance From Shore (m)	Depth (cm)	Species	Height (cm)	Cover %
25	40	*E. acicularis*	4	30
		I. muricata	5	10
		P. gramineus	25	10
		P. Richardsonii	20	80
30	45	*E. acicularis*	2	10
		I. muricata	3	20
		P. gramineus	20	10
		P. Richardsonii	25	80
		S. angustifolium	∿110	40
35	55	*E. acicularis*	2	10
		I. muricata	3	10
		P. gramineus	30	20
		P. Richardsonii	25	60
		S. angustifolium	∿ 55	negl.
40	80	*I. muricata*	4	50
		P. gramineus	40	20
		P. Richardsonii	25	30
45	105	*I. muricata*	5	100
		P. Richardsonii	50	20
50	125	*I. muricata*	6	80
		P. Richardsonii	90	30
55	155	*I. muricata*	6	50
		P. Richardsonii	100	20
60	255	*I. muricata*	10	50
		P. Richardsonii	100	20
65	345	*P. Richardsonii*	150	10
		Transect 5		
5	20	no plants		
10	35	*E. acicularis*	2	negl.
		I. muricata	2	negl.
		P. gramineus	10	negl.
15	42	*P. filiformis*	10	5
		P. gramineus	10	10

(continued)

TABLE A-4 (continued)

Distance From Shore (m)	Depth (cm)	Species	Height (cm)	Cover %
20	55	*P. filiformis*	10	5
		P. gramineus	10	10
		P. Richardsonii	30	negl.
25	85	*I. muricata*	3	negl.
		P. filiformis	10	5
		P. gramineus	10	10
		P. Richardsonii	30	negl.
30	95	*P. filiformis*	10	negl.
		P. Richardsonii	20	5
35	110	*E. acicularis*	4	80
		P. filiformis	10	5
		P. Richardsonii	40	5
40	120	*E. acicularis*	4	40
		P. Richardsonii	100	30
45	135	*P. Richardsonii*	100	50
50	140	*P. Richardsonii*	100	50
55	150	*P. praelongus*	120	20
		P. Richardsonii	100	40
60	175	*P. praelongus*	130	10
		P. Richardsonii	100	50
65	200	*P. praelongus*	150	40
		P. Richardsonii	80	40
70	240	*Chara* sp.	10	negl.
		P. praelongus	150	20
		P. Richardsonii	30	negl.
75	270	*P. praelongus*	100	negl.
		P. Richardsonii	20	negl.
		Transect 6		
5	30	no plants		
10	40	no plants		
15	50	no plants		
20	70	*P. Richardsonii*	25	40
25	90	*P. Richardsonii*	25	40

(continued)

TABLE A-4 (continued)

Distance From Shore (m)	Depth (cm)	Species	Height (cm)	Cover %
30	110	no plants		
35	120	no plants		
40	135	no plants		
45	150	*Ranunculus* sp.	2	negl.
50	165	*P. Richardsonii*	100	5
55	175	*I. muricata* *P. Richardsonii*	6 100	10 30
60	180	*P. Richardsonii*	90	15
65	185	*P. filiformis*	10	negl.
70	205	no plants		
75	230	no plants		
80	245	no plants		
85	260	no plants		
90	275	*P. Richardsonii*	100	30
95	300	*P. Richardsonii*	100	60
100	320	*P. Richardsonii*	100	30
105	330	*P. Richardsonii*	50	5
110	350	*P. Freisii* *P. Richardsonii*	20 100	50 5
115	365	*P. Freisii*	20	50
120	380	*P. Freisii*	20	negl.
125	400	*P. Freisii*	20	negl.
130	420	*P. Freisii*	20	negl.